Daytime Dynamo Rocket Investigation

Launches of July 10, 2011 and July 4, 2013

Motivation of the Dynamo Experiment

→ The Dynamo Paradigm and Conundrum

Robert Pfaff (and the Dynamo Team)
NASA/Goddard Space Flight Center

Daytime Dynamo "Workshop"

St. Michaels, Maryland

March 3-5, 2015

Daytime Dynamo Rocket Investigation

Dynamo Science Team

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Clemson University

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Neil Murphy
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Vassilis Angelopoulos, Hannes Leinweber, Ivan Bernal, Peter Chi
UCLA

Takumi Abe, Hiroto Habu, Masa-Yuki Yamamoto, Shigeto Watanabe, Mamoru Yamamoto, Tatsuhiro Yokoyama, Yosuke Yamazaki, Yoshihiro Kakinami
ISAS/JAXA

Dynamo Rocket Campaigns:

21.140 (July 4, 2013) and 21.141 (July 10, 2011)

- **Ground-based Observations**

  Magnetometer (GSFC and UCLA/Falcon Magnetometer)
  Ionosonde and VIPIR (Terry Bullett)

- **In-situ Magnetometer Data and Current Calculations**

  GSFC Fluxgate Magnetometer (Rob Pfaff, Doug Rowland, GSFC)
  JPL/UCLA Magnetometer (Neil Murphy, JPL, Vassilis Angelopoulos, UCLA)

- **Electric Field Observations** (Rob Pfaff, Doug Rowland, GSFC)

- **Plasma Density Observations**

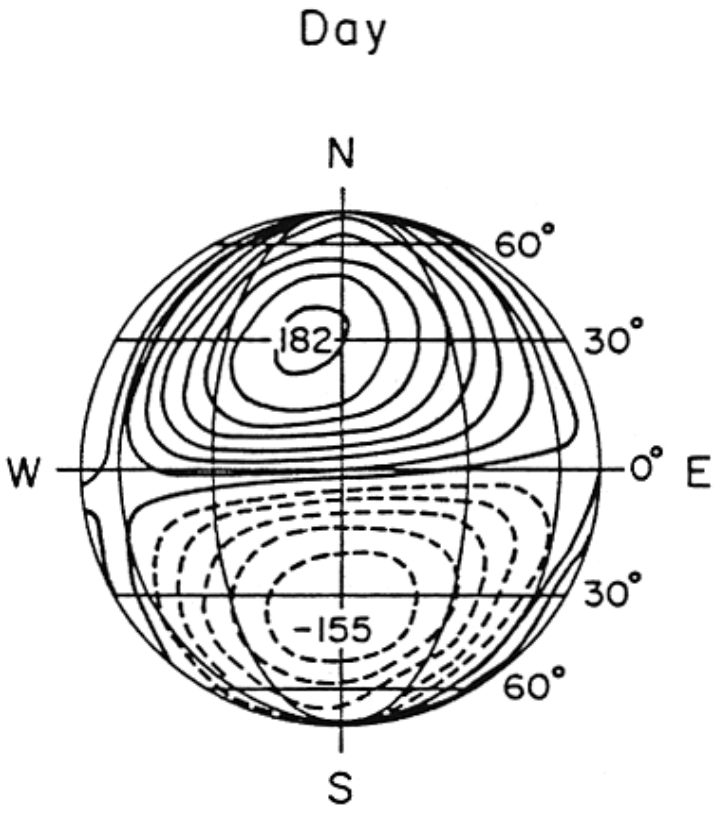
  Langmuir Probe (Jeff Klenzing, GSFC)
  Impedance Probe (Doug Rowland, GSFC)

- **Neutral Density, Temperature, Composition, Winds** (Jim Clemmons, Aerospace)

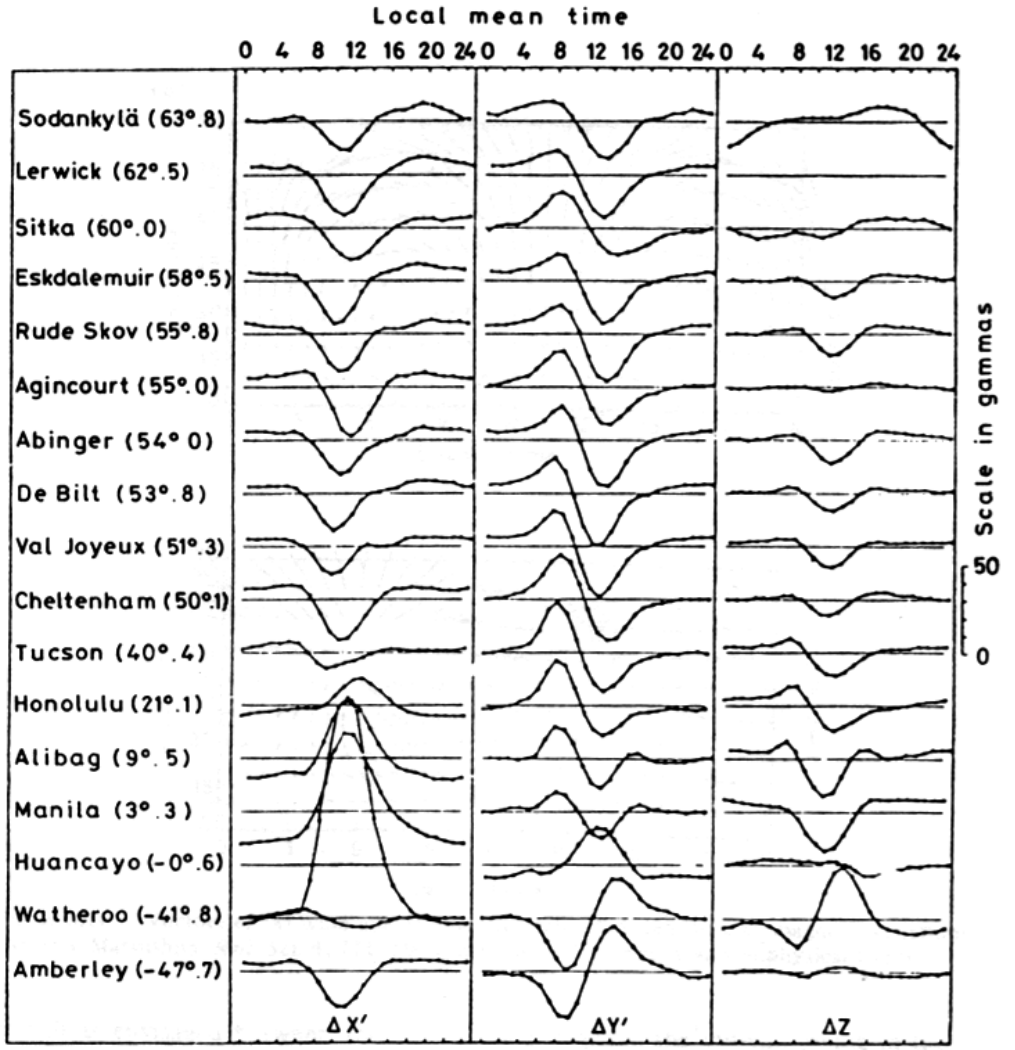
- **Lithium wind observations** (Miguel Larsen, Clemson; T. Abe, H. Habu, + others, JAXA)

- **Atmosphere Data from Falling Sphere Experiment** (Chad Fish, USU)

Remarks on the “Dynamo” Process



Matsushita, 1965



[Vestine, 1960]

Early Modeling Work showed tidal winds could account for observed Sq current patterns

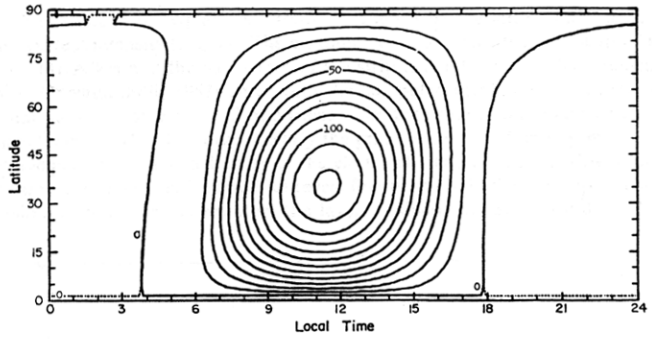


FIG. 7. ELECTRIC CURRENT GENERATED BY THE SOLAR DIURNAL (1,−1) MODE. The contour interval is 10,000 A. The current is in a counterclockwise direction.

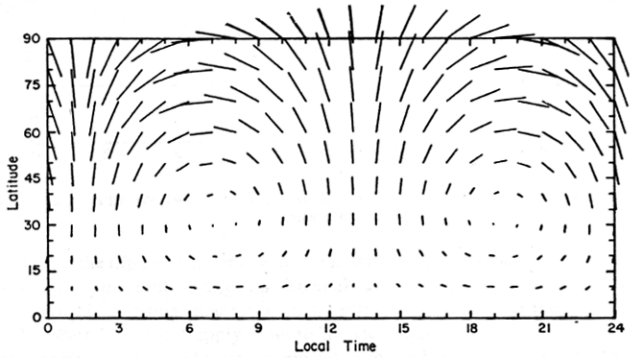
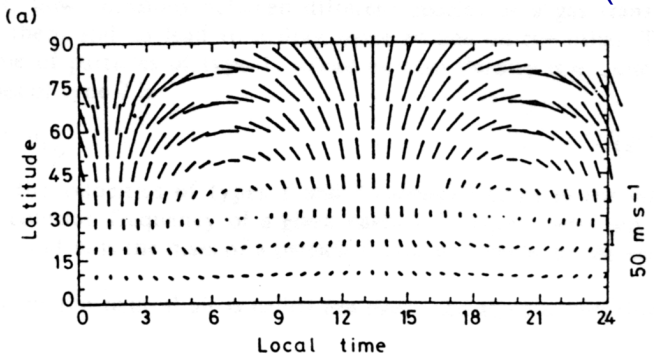


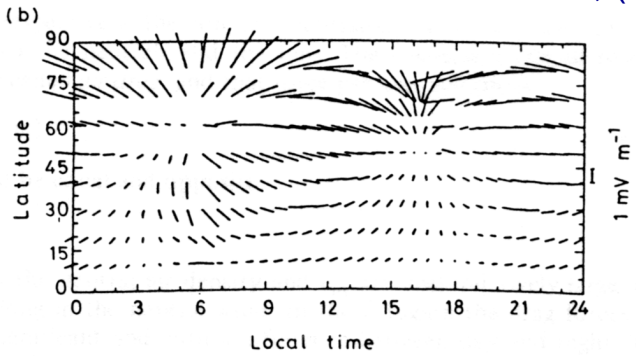
FIG. 8. DISTRIBUTION OF THE SOLAR DIURNAL (1,−1) WIND FIELD WHICH DRIVES THE CURRENT SYSTEM ILLUSTRATED IN FIG. 7.
A distance equal to 5 deg of latitude represents a wind speed of 50 m/sec.

Tarpley, 1970

Tidal Winds (Model)

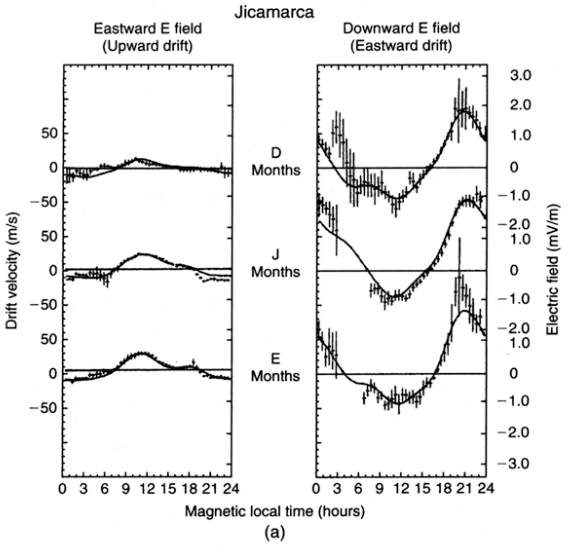


Electric Fields, (Model)

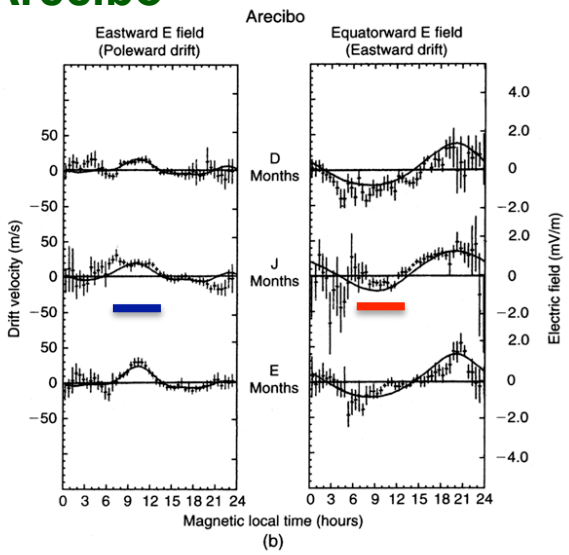


Matsushita, 1969

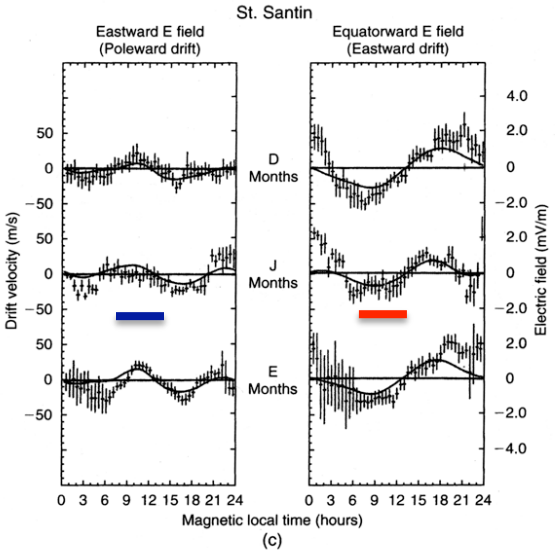
Jicamarca



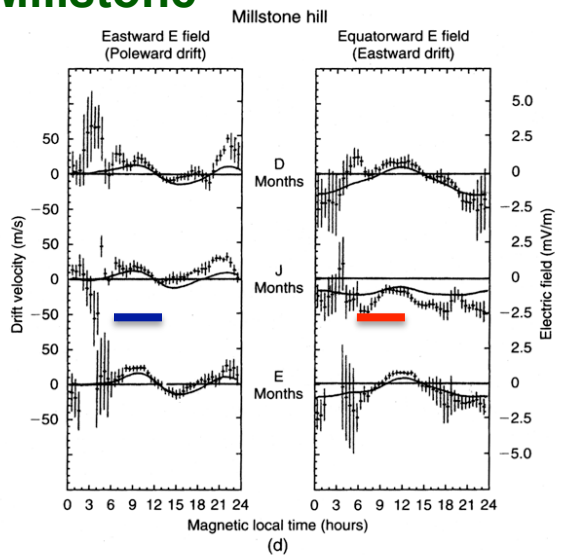
Arecibo



St Santin



Millstone



Pre-noon fields -- Summer, Mid-Latitudes:

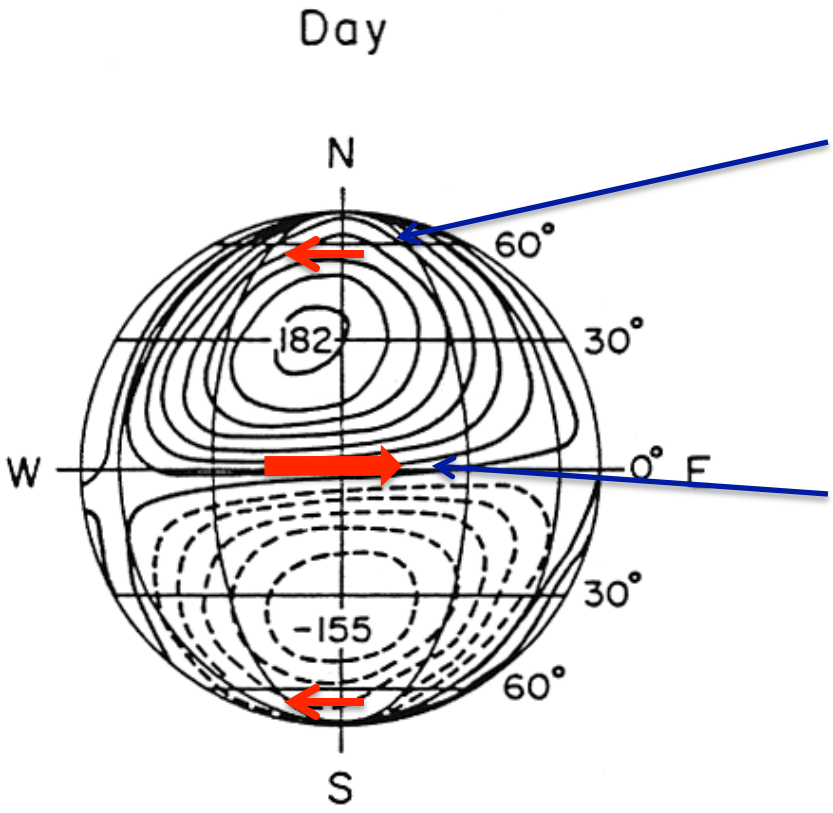
— **Poleward**

— **Eastward**

"Ambient" **E** x **B** is Northwest

Mid-latitude electric fields are basically diurnal

[Richmond et al., 1980; See also Kelley, 2009]



Matsushita, 1965

Westward Current

Negative Delta Bx on ground

Is there a corresponding, local equatorward DC electric field to drive a corresponding eastward **E** x **B**?

Equatorial Electrojet (**Eastward** Current)

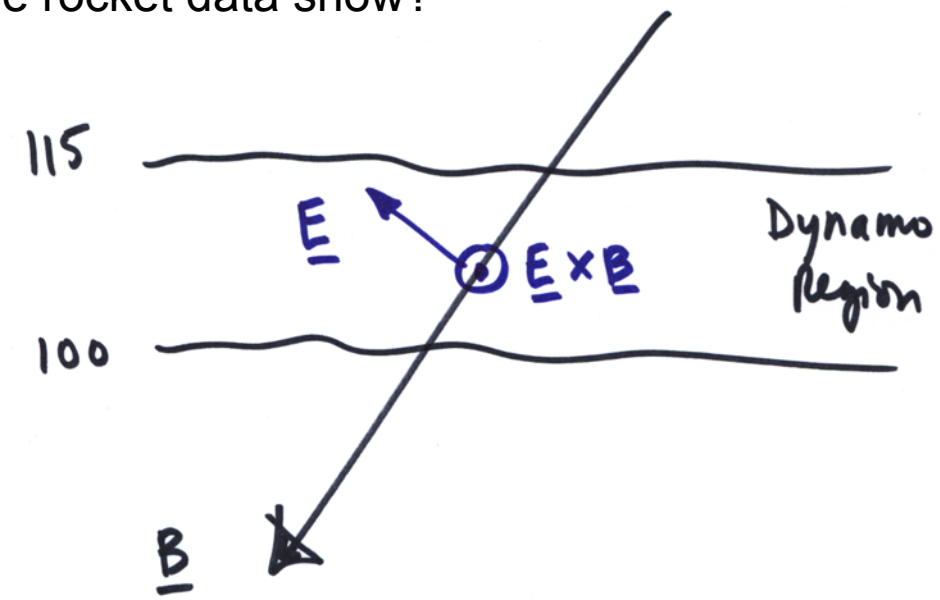
Positive Delta Bx on ground

Upwards Polarization E-field in Region from 95 to 115 km drives Eastward Hall Current (Westward **E** x **B** Drift)

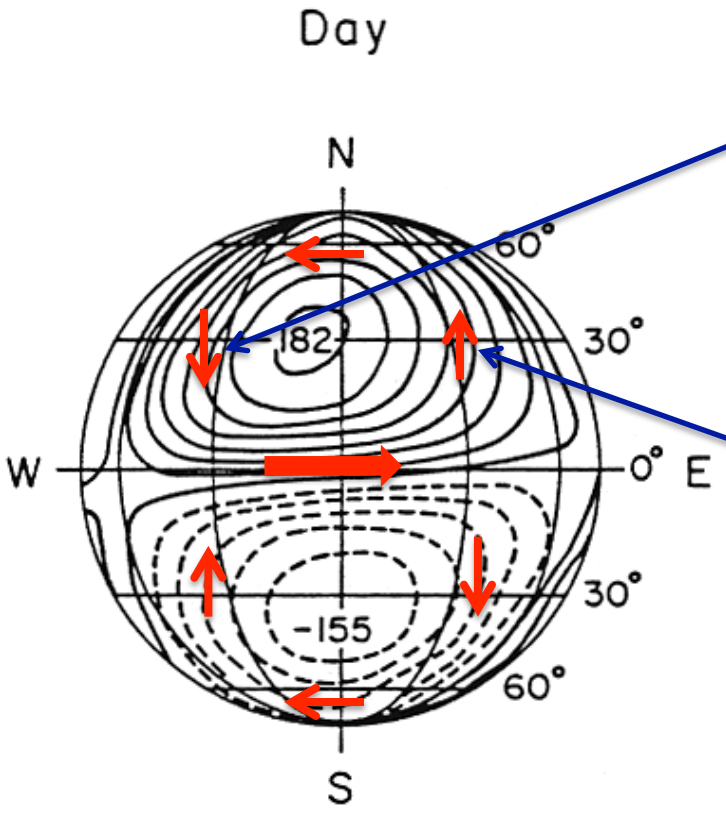
- Radar data show there is NOT an equatorward E associated with the westward mid-latitude dynamo current (driven by **E** x **B** eastward).

- Rather, the radar data show the prevailing electric field that maps down to this region is poleward, driving a dynamo current in the opposite direction to the observed currents on the ground.

- What does the rocket data show?



Epoleward produces a westward **E** x **B** drift in the dynamo region that would drive an eastward current, opposite to the westward zonal current observed on the ground.



Matsushita, 1965

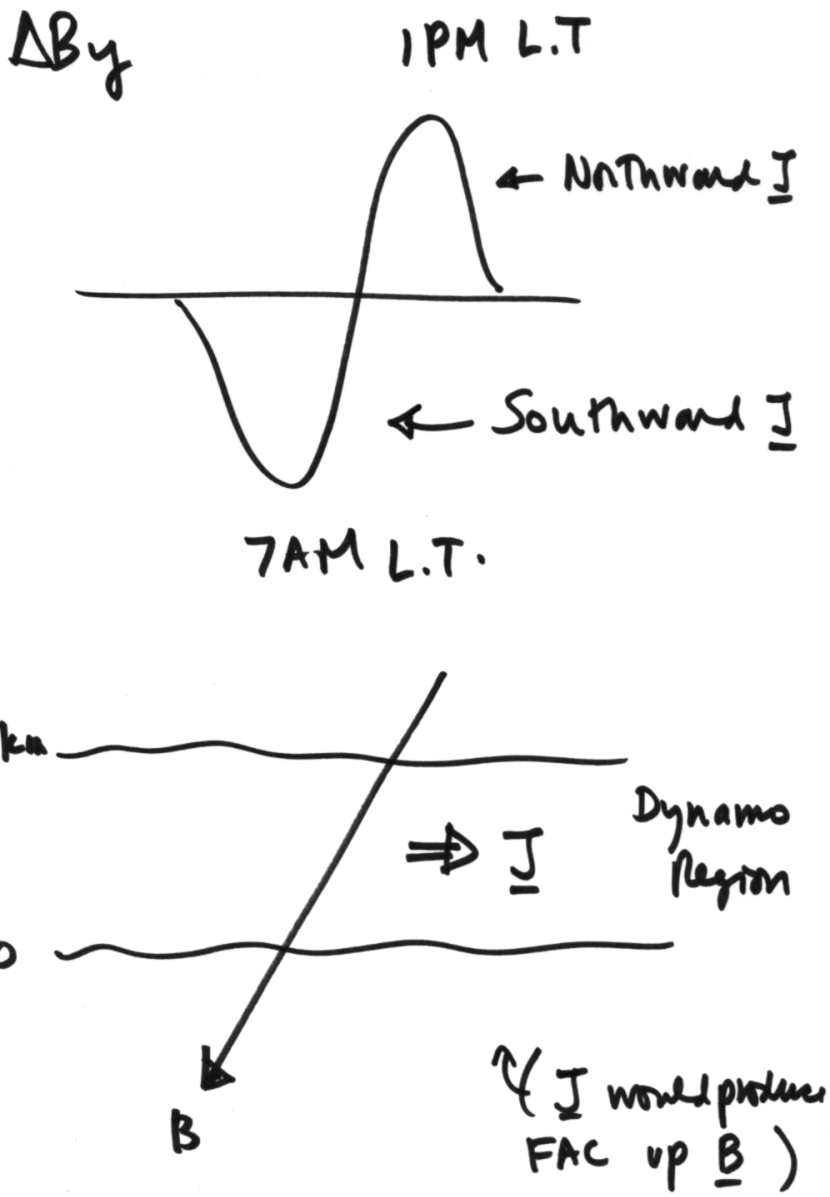
Equatorward Current

Negative Delta By on ground

Poleward Current

Positive Delta By on ground

Upwards Polarization E-field in Region from 95 to 115 km drives Eastward Hall Current (Westward **E** x **B** Drift)


ΔBy
1PM L.T
← Northward J
← Southward J
7AM L.T.
115km
100
⇒ J
Dynamo Region
B
↻ (J would produce FAC up B)

Ionospheric currents are governed by the dynamo equation:

$$\mathbf{J} = \underline{\sigma} \bullet (\mathbf{E} + \mathbf{U} \times \mathbf{B})$$

Hence, to understand how the currents are set up, we must measure:

- Currents (**J**)
- Conductivity tensor ($\underline{\sigma}$) which depends on plasma density (N_e) and ion and electron mobilities. The mobilities depend on neutral density, ion and neutral species, temperatures.
- DC electric field (**E**)
- Neutral winds (**U**)
- Magnetic field (**B**)

→ Earth's "dynamo" currents are driven by neutral winds and electric fields and depend on plasma density and mobilities.

$$
\begin{aligned}
\mathbf{J} &= \sigma_P \left(\mathbf{E}_\perp + \mathbf{u} \times \mathbf{B}\right) \\
&\quad + \sigma_H \hat{b} \times \left(\mathbf{E}_\perp + \mathbf{u} \times \mathbf{B}\right) + \sigma_\circ \mathbf{E}_\parallel \\
\sigma_P &= e^2 \sum_j \frac{n_j \nu_j}{m_j(\nu_j^2 + \Omega_j^2)} \\
\sigma_H &= e^2 \sum_j \frac{-n_j \Omega_j}{m_j(\nu_j^2 + \Omega_j^2)} \\
\sigma_\circ &= e^2 \sum_j \frac{n_j}{m_j \nu_j}
\end{aligned}
$$

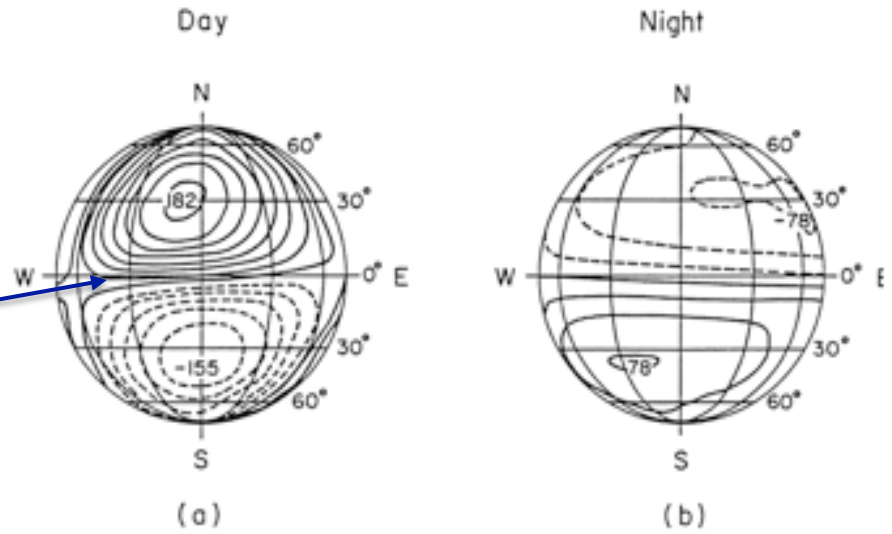
A few other things to consider…before we begin

- **Lunar Tides affect Sq Current**
  - Not dominant; Not yet studied in current data
- **Magnetic Activity/Storm effects**
  - Obscure Ground-based current signatures
  - Can produce enhanced Sq currents
- **Metallic Layers offer important clues**
  - Enhanced in the summer
  - Indicative of wind shear?

Earth's ionosphere includes world wide "dynamo" current patterns

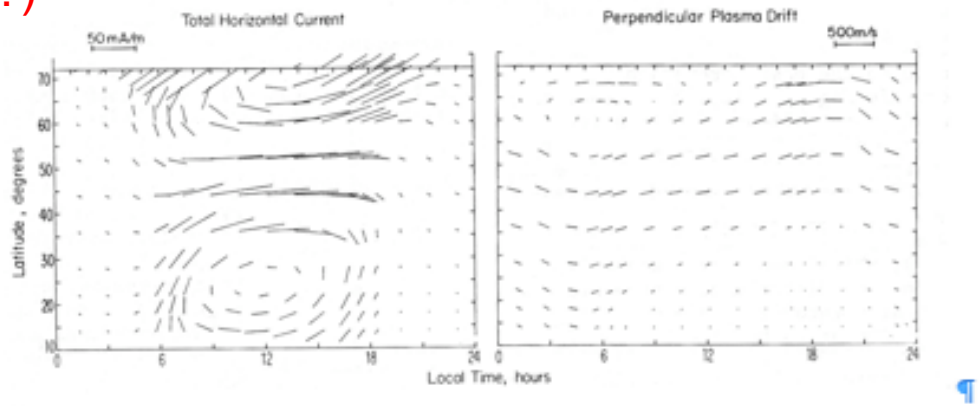
Quiet

Equatorial Electrojet



Matsushita, 1965

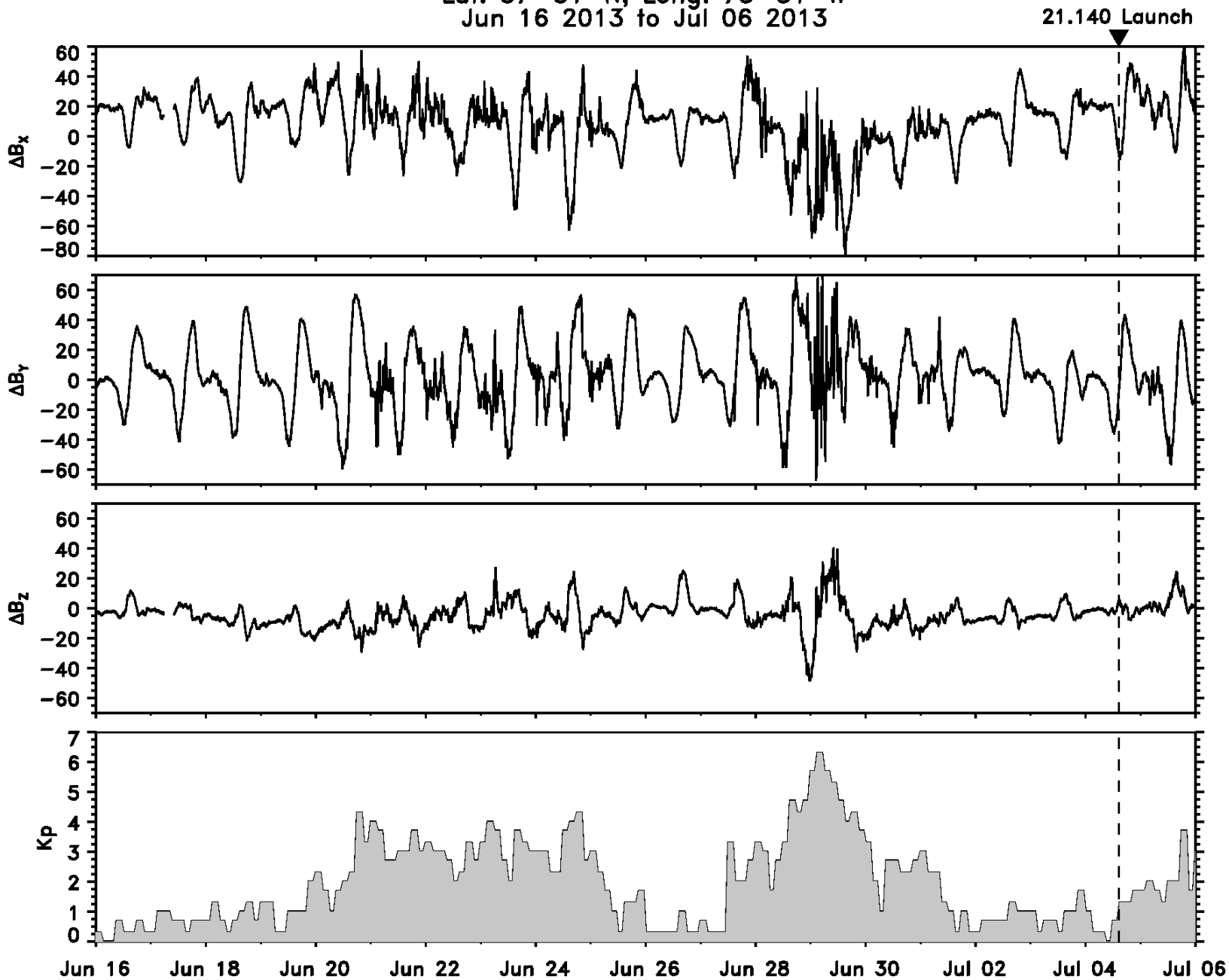
Disturbed (?)

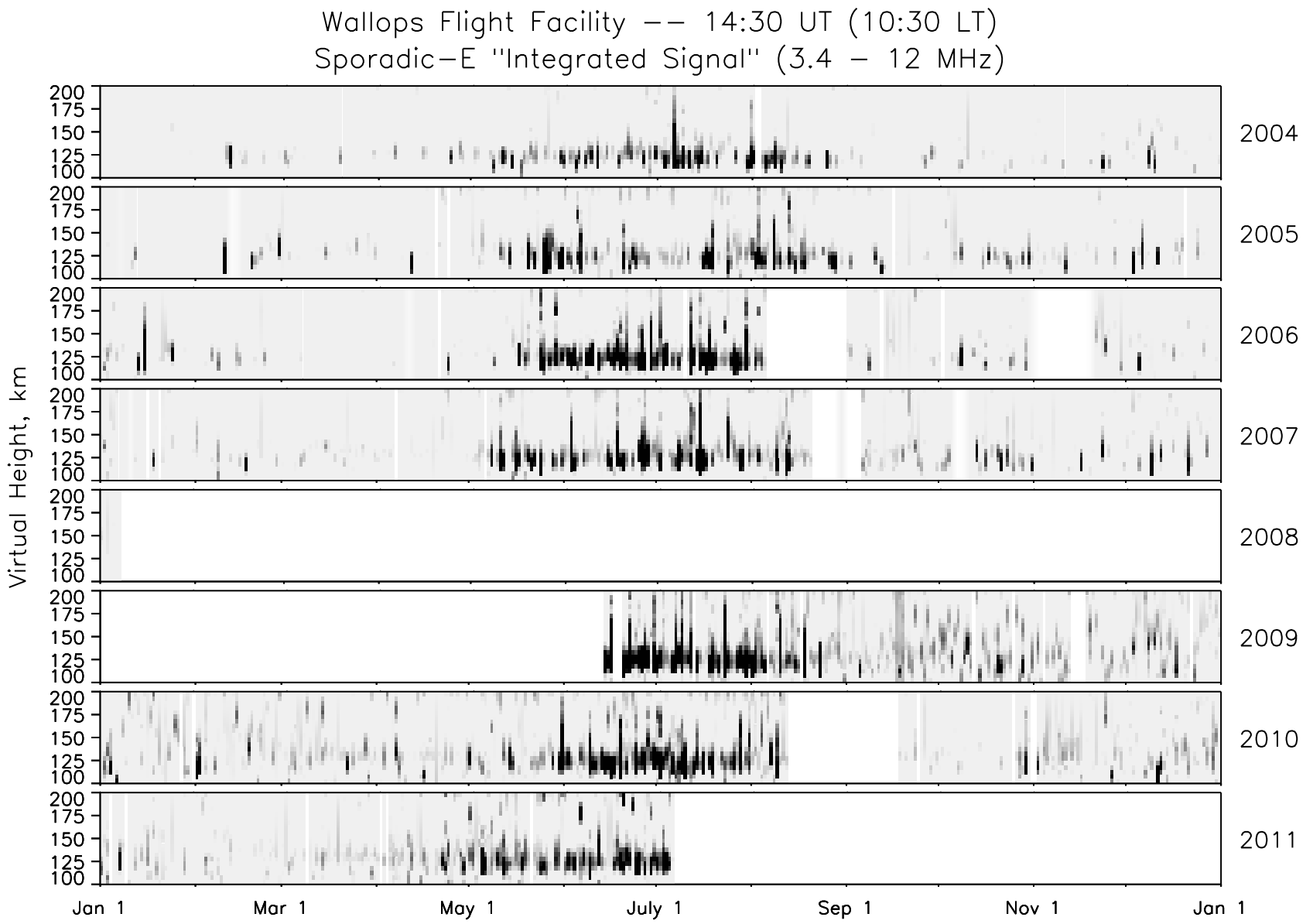


Blanc and Richmond [1980]

What does the pattern look like during a magnetic storm?

Is this controlled by Winds or Electric fields or both?


GSFC Magnetometer -- Wallops Flight Facility (USA)
Lat: 37° 51' N, Long. 75° 31' W
Jun 16 2013 to Jul 06 2013
21.140 Launch
ΔBx
ΔBy
ΔBz
Kp
60
40
20
0
−20
−40
−60
−80
7
6
5
4
3
2
1
0
Jun 16
Jun 18
Jun 20
Jun 22
Jun 24
Jun 26
Jun 28
Jun 30
Jul 02
Jul 04
Jul 06



CL, Jul 07 2011 09:59:39
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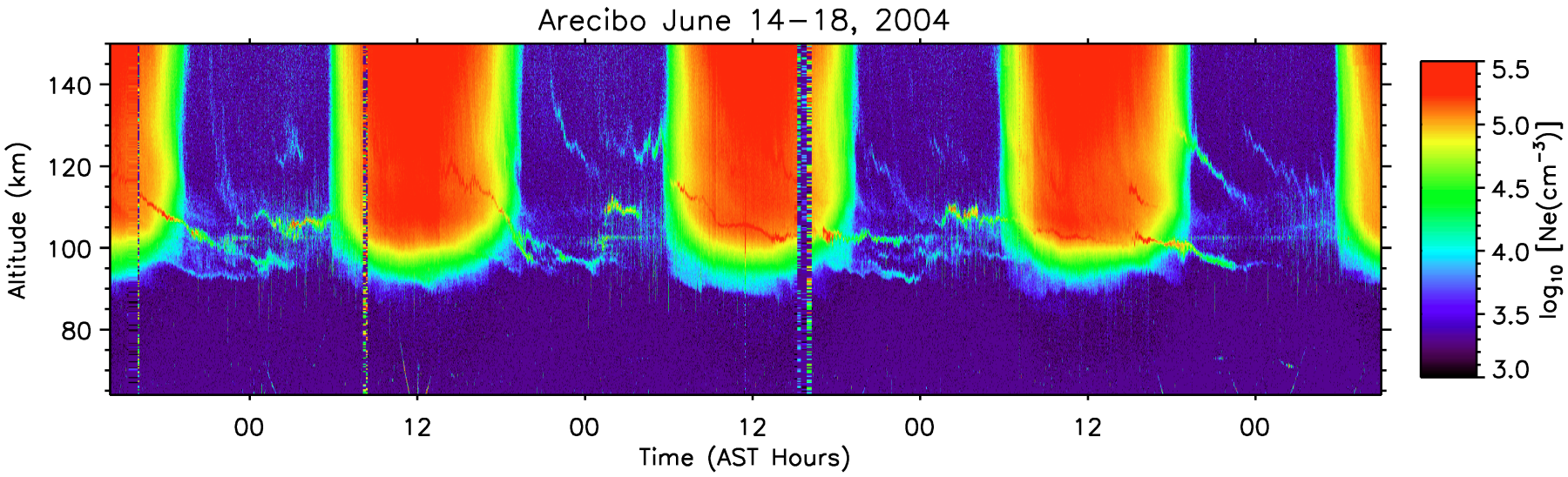
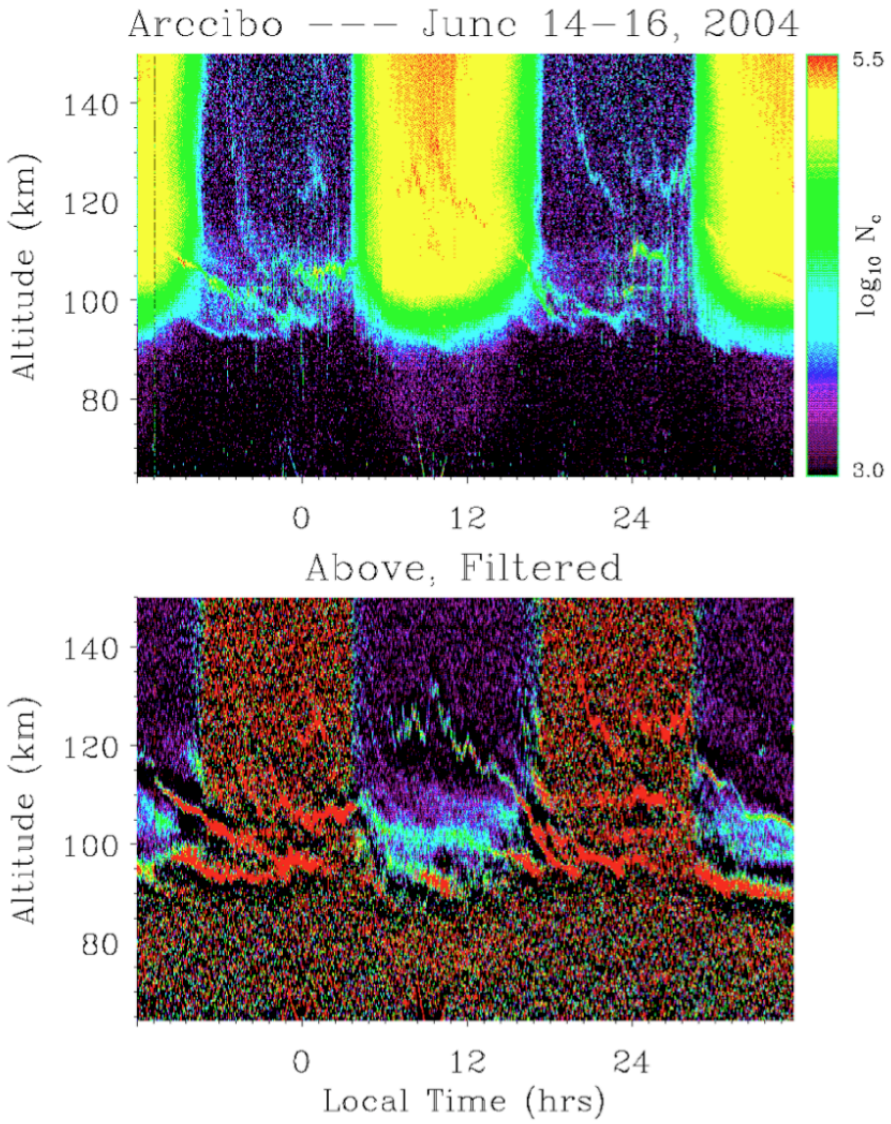

Arecibo June 14–18, 2004
Altitude (km)
140
120
100
80
00
12
00
12
00
12
00
Time (AST Hours)
5.5
5.0
4.5
4.0
3.5
3.0
log10 [Ne(cm-3)]

Arecibo Observatory data show that such metallic layers are common during the day -- We can expect their presence at Wallops as well.



Questions

1. How significantly do daytime sporadic-E layers alter the conductivity and hence the current?
2. Do these layers provide evidence of wind shears?

Questions/Observations at the onset…
Large scale relationships…

- For Poleward electric fields, the resulting **E** x **B** Hall current is eastward…yet Sq patterns clearly show westward currents…Thus, winds must be needed (or the E-fields are not poleward.)
- TMA trails consistently show large amplitude winds at night with large shears…what happens in the daytime?
- If sporadic-E layers are prevalent in the daytime, does this imply large wind shears?
- If the measured ground based J is large during disturbed periods, does this imply large electric fields, neutral winds, or both?
- Can not Sq patterns yield critical knowledge of daytime winds and electric fields, beyond tides? Look at discrepancies with tidal predictions, particularly during storms?

Questions/Observations at the onset…

The Dynamo Conundrum…

- The Sq current observations are consistent with those driven by tides….
- But maybe, there are large winds, countered by large electric fields, and so the tidal “explanation” is missing some of the key physics?
- Is there a way to compare the Sq currents with models to deduce the fields/winds?
  - Fields change quickly, winds do not (True?)
  - -- Fields map to other regions → Contribute to global electrodynamics…

Questions/Observations at the onset…
Localized Electrodynamics…

- Is there any evidence for a polarization electric field within the enhanced layer of Hall conductivity? (Similar to Cowling conductivity in the equatorial electrojet?)
- Does J maximize at the altitude of the enhanced conductivity (implying that it is driven by ExB) or at another height, perhaps controlled by the wind?
- How do sporadic-E layers affect the current? Do they “short out” the applied electric fields (similar to enhanced auroral conductivity effects on electric fields)?
- If there is a wind shear present, does this affect the localized electric field?

Dynamo I Campaign

Wallops Island, Va.

July, 2011

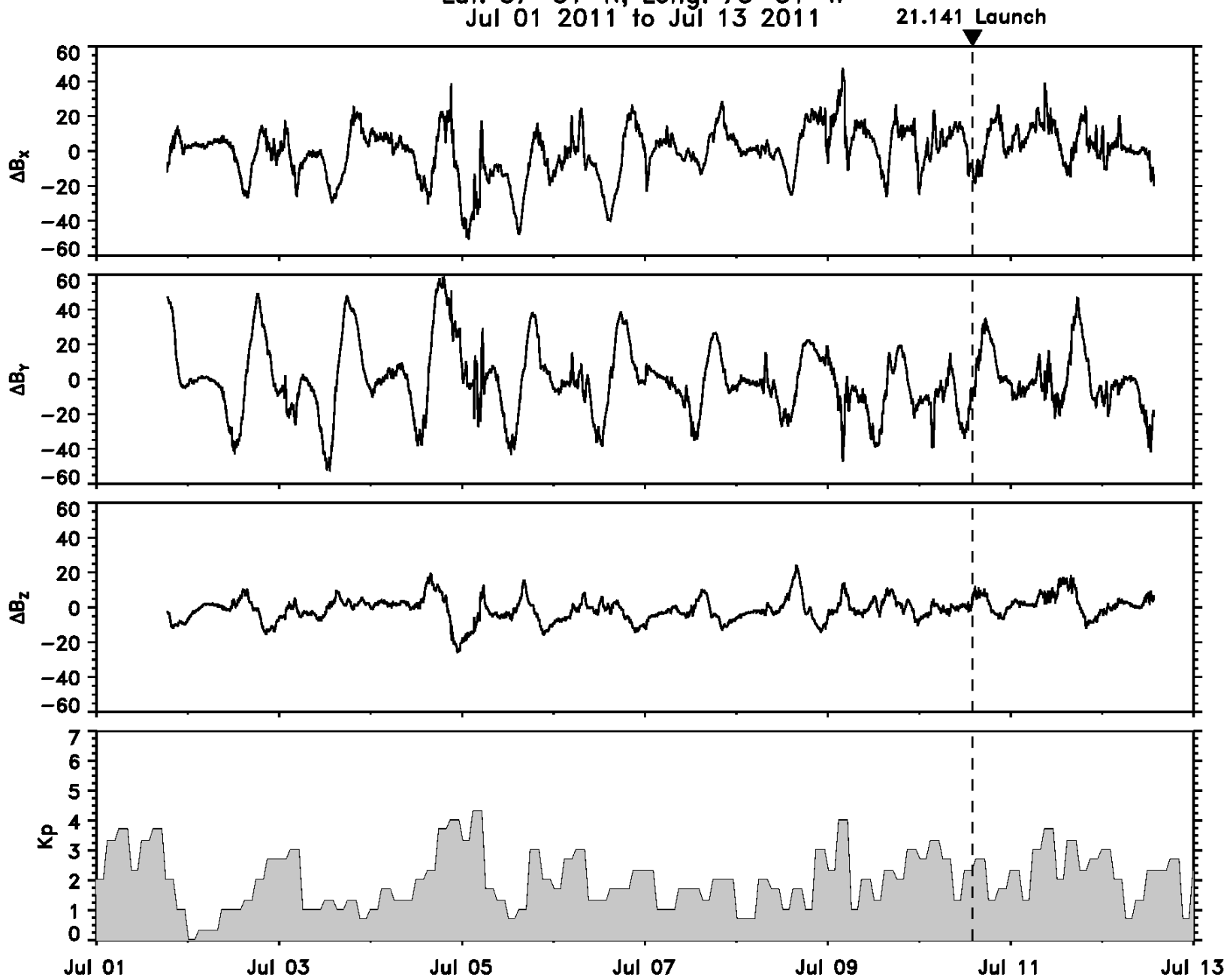
Ground-Based Observations

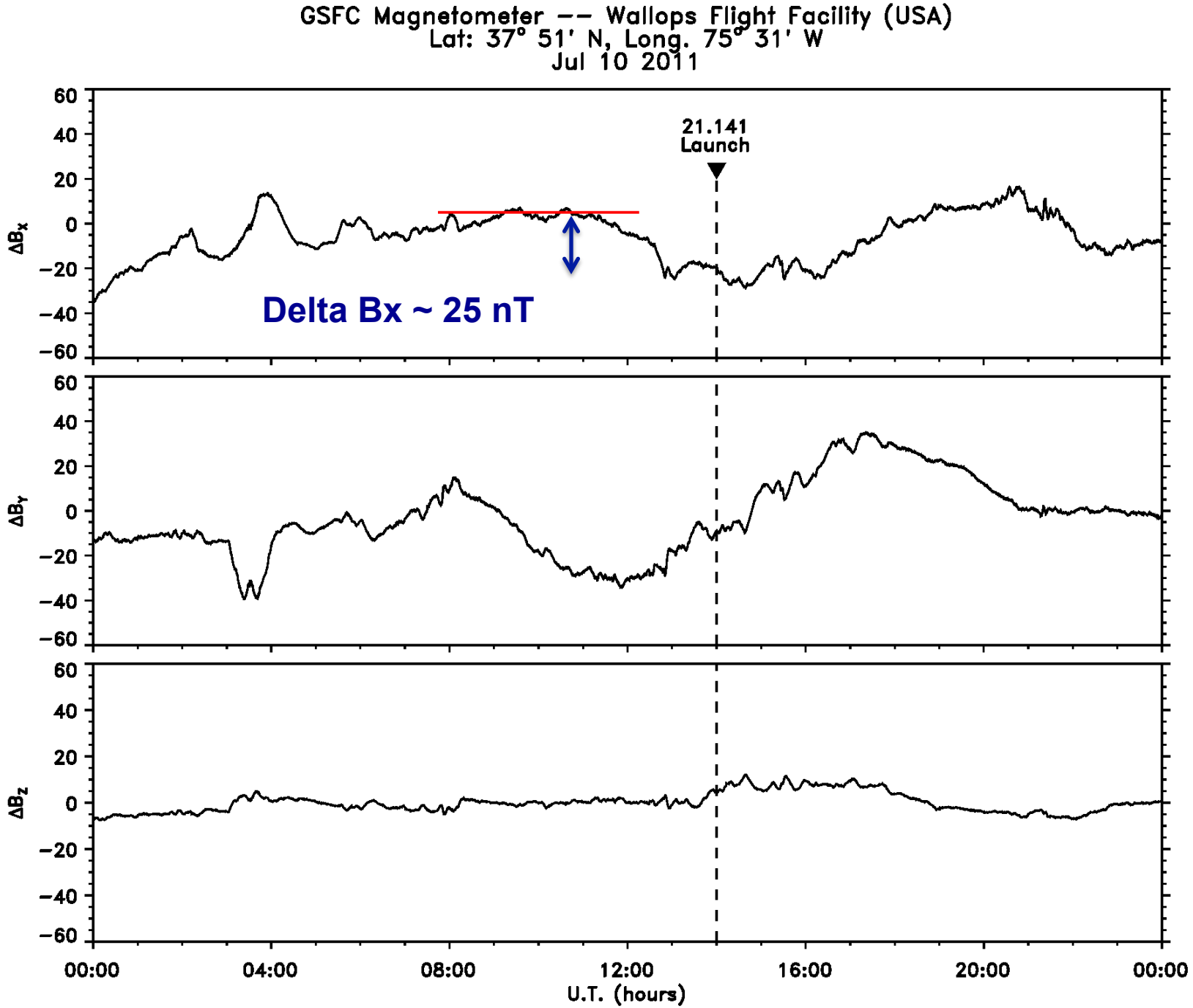
Rockets 21.141 and 41.091

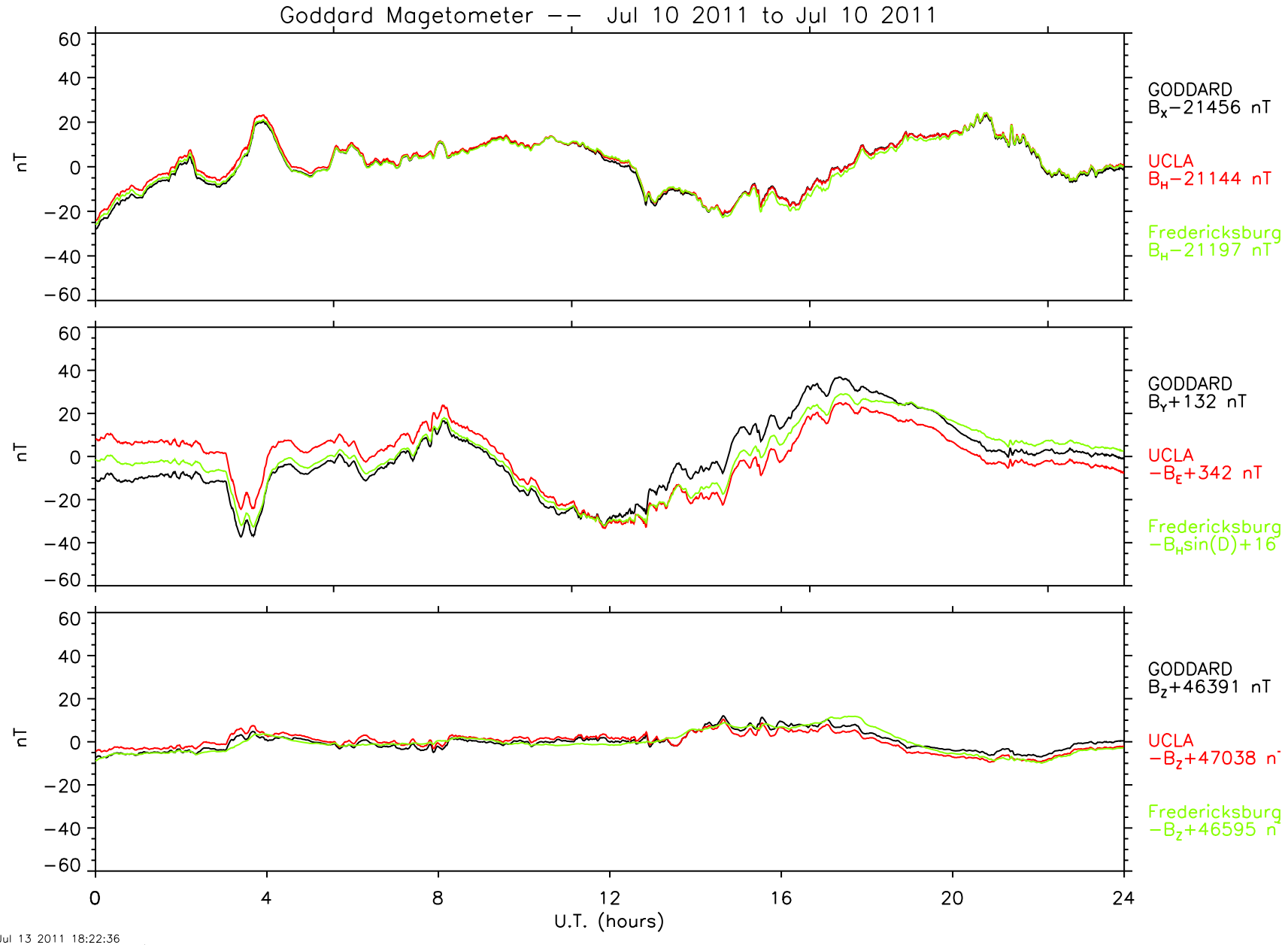
Launches of July 10, 2011

Ground-Based data -- Real-Time Displays at Operations Console

Wallops Flight Facility, Virginia


GSFC Magnetometer -- Wallops Flight Facility (USA)
Lat: 37° 51' N, Long. 75° 31' W
Jul 01 2011 to Jul 13 2011
21.141 Launch
ΔBx
ΔBy
ΔBz
Kp
60
40
20
0
−20
−40
−60
7
6
5
4
3
2
1
0
Jul 01
Jul 03
Jul 05
Jul 07
Jul 09
Jul 11
Jul 13


GSFC Magnetometer -- Wallops Flight Facility (USA)
Lat: 37° 51' N, Long. 75° 31' W
Jul 10 2011
21.141
Launch
Delta Bx ~ 25 nT
ΔBx
ΔBy
ΔBz
60
40
20
0
−20
−40
−60
00:00
04:00
08:00
12:00
16:00
20:00
00:00
U.T. (hours)



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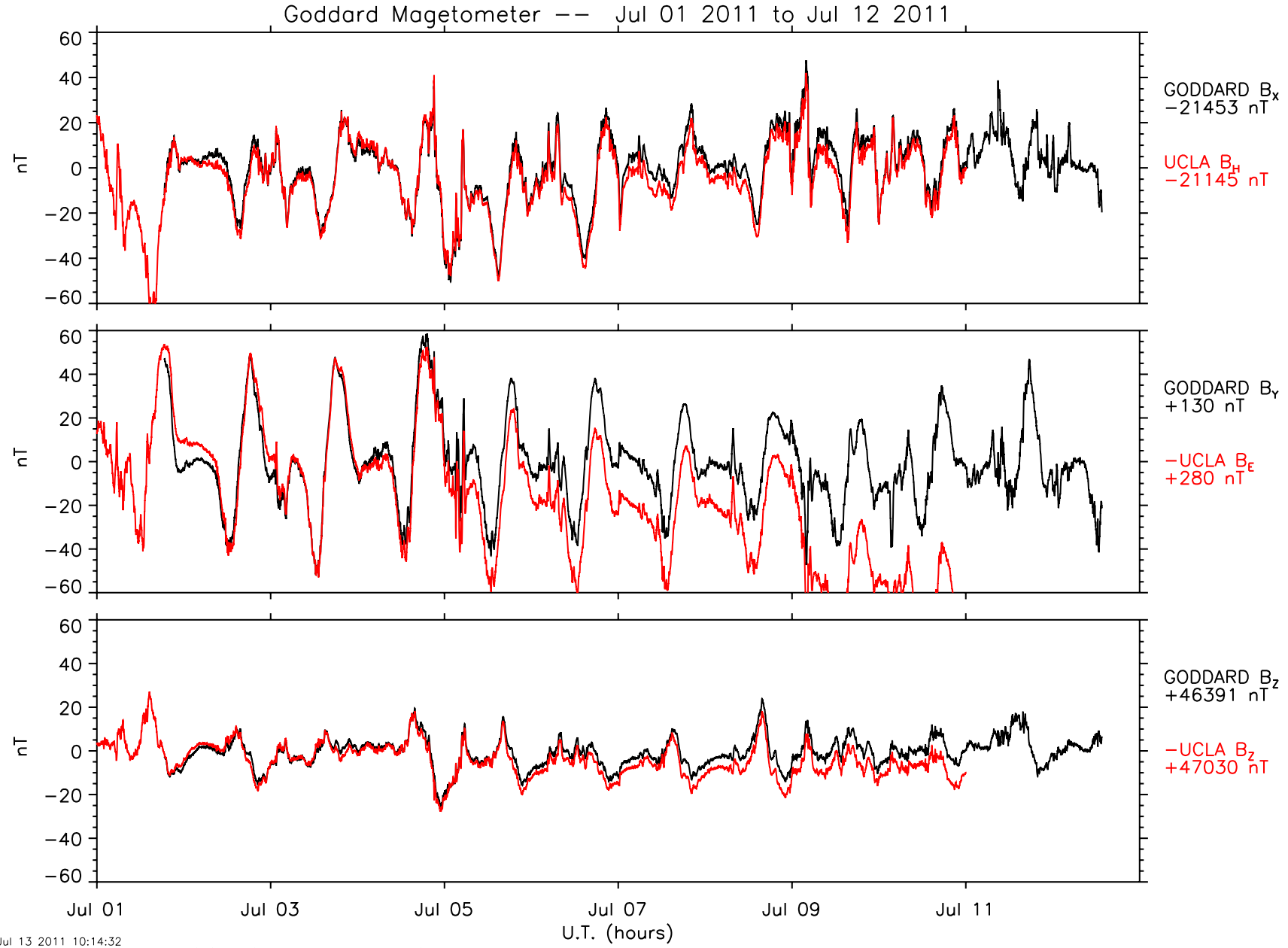

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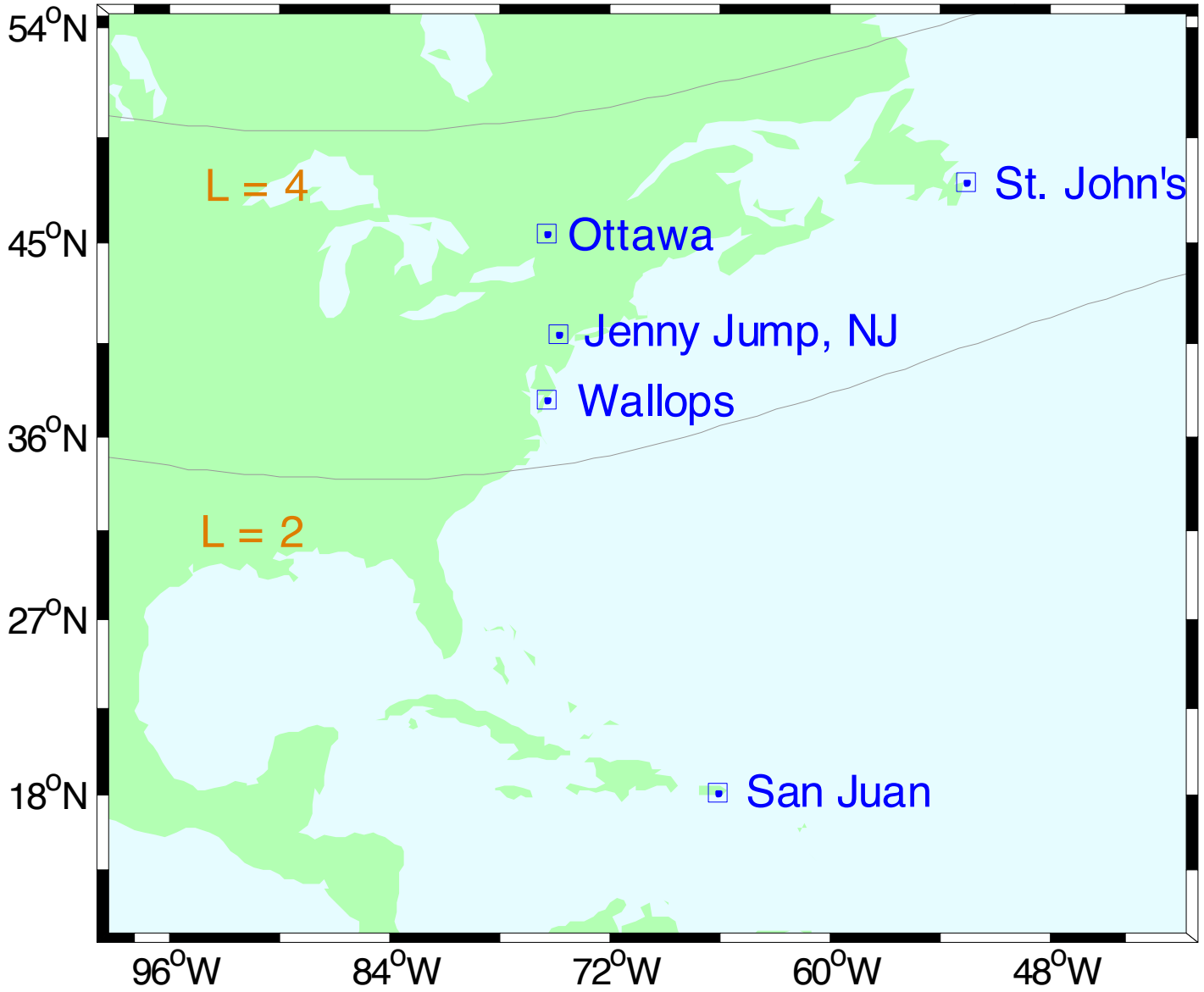
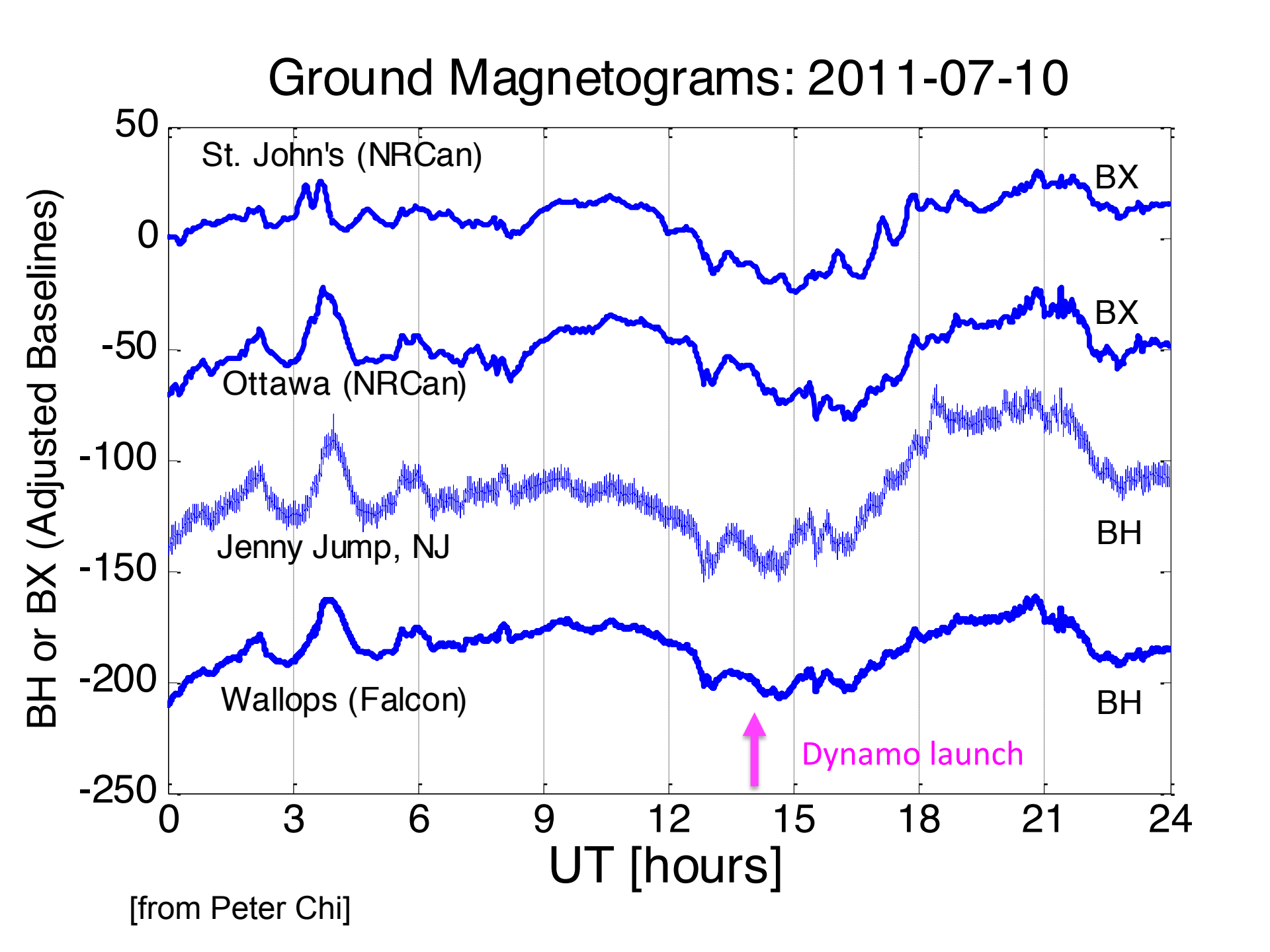
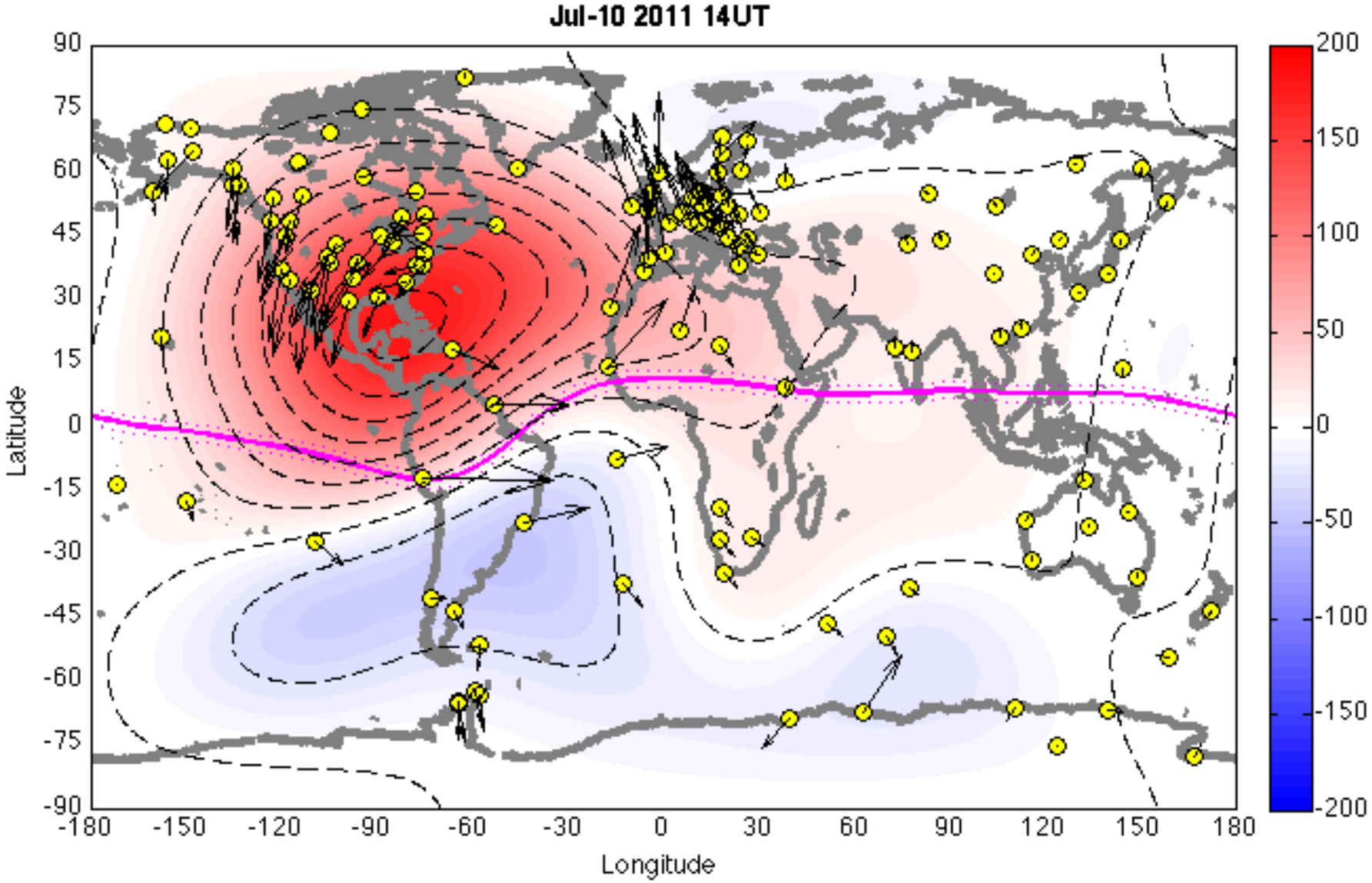


[from Peter Chi]

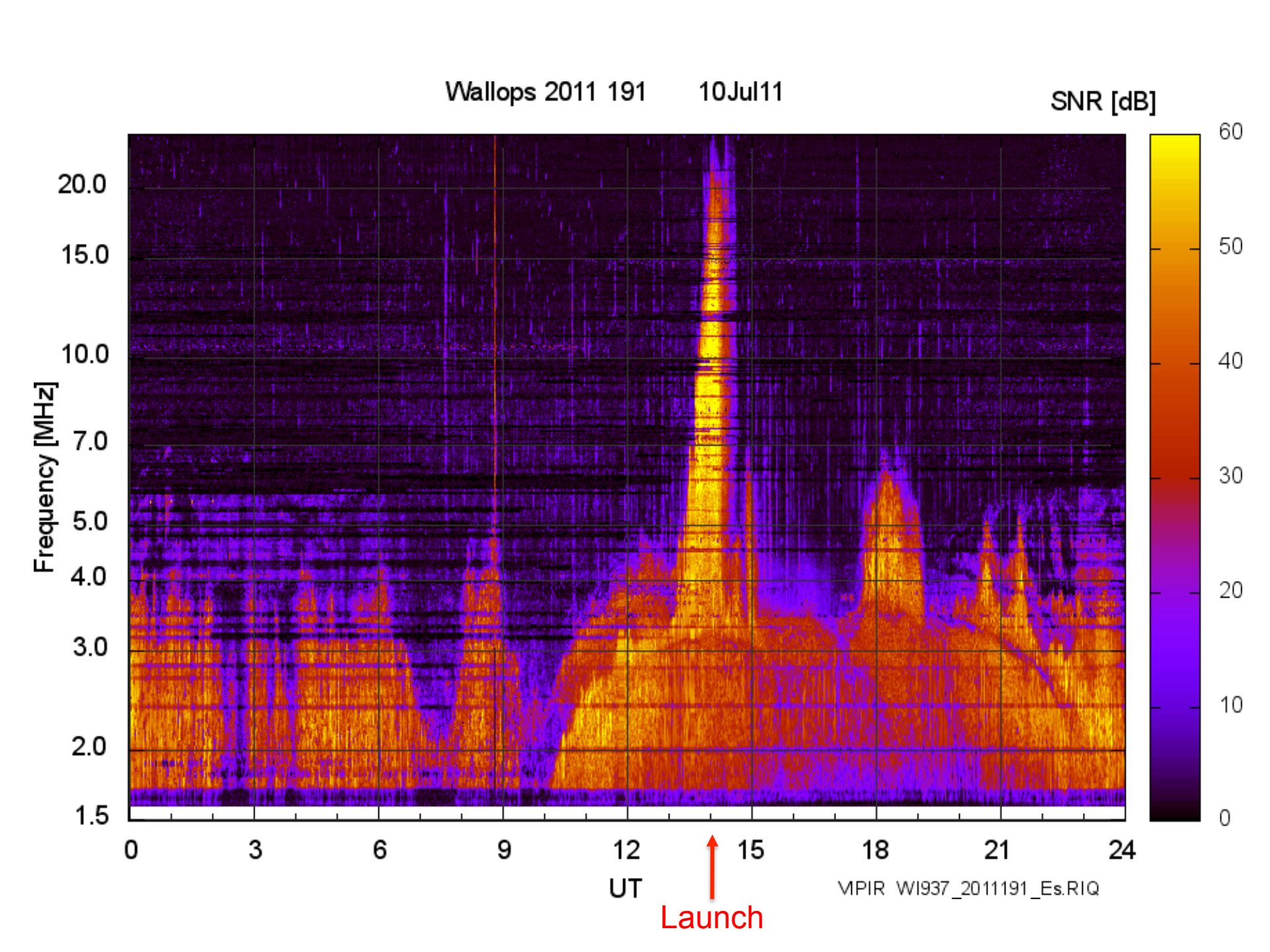


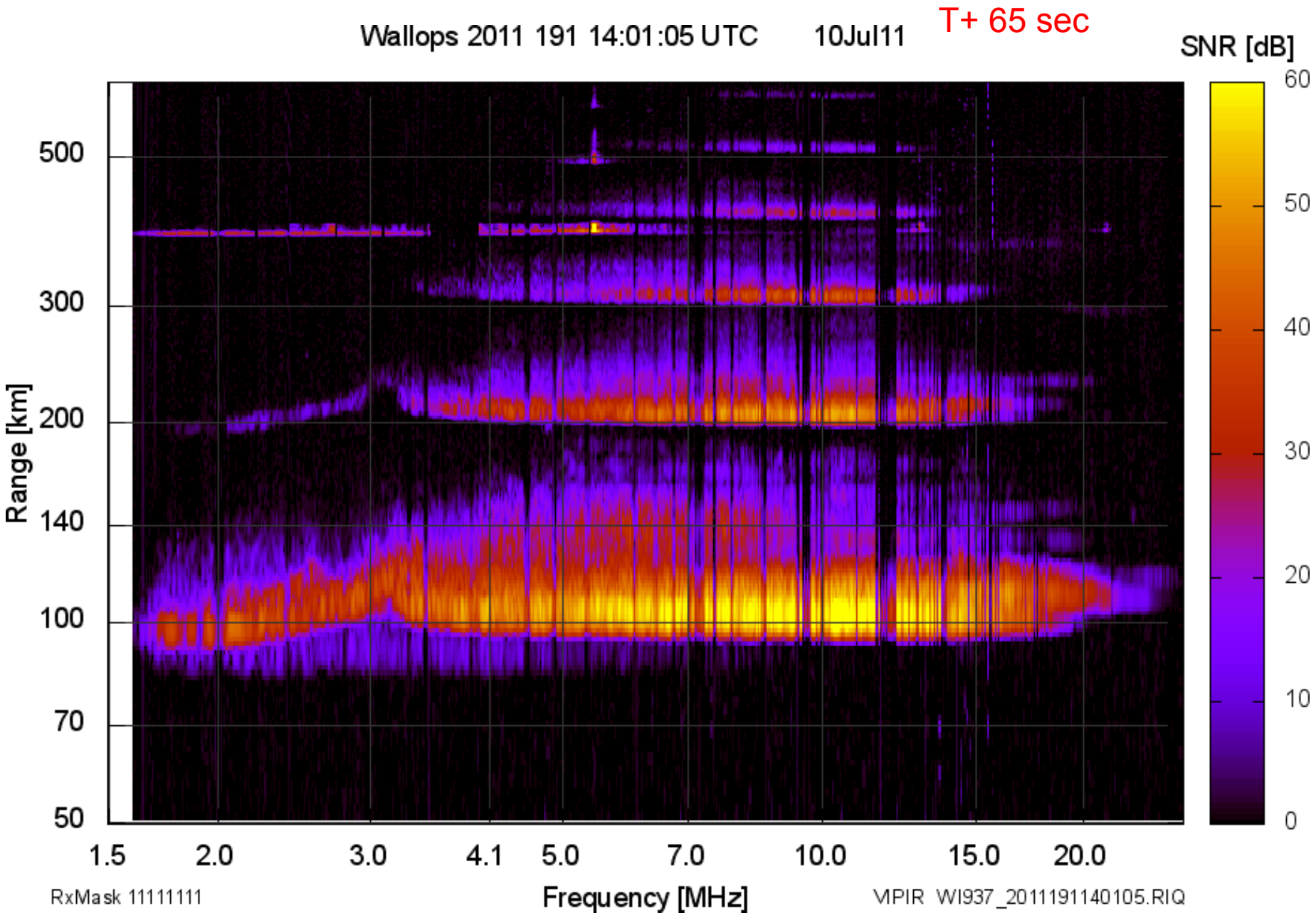
[from Peter Chi]

Current Patterns Derived from Ground-based Magnetometer Data



(Yosuke Yamazaki, Lancaster, UK)


Wallops 2011 191 10Jul11
SNR [dB]
60
50
40
30
20
10
0
Frequency [MHz]
20.0
15.0
10.0
7.0
5.0
4.0
3.0
2.0
1.5
0
3
6
9
12
15
18
21
24
UT
Launch
VIPIR WI937_2011191_Es.RIQ


Wallops 2011 191 14:01:05 UTC
10Jul11
T+ 65 sec
SNR [dB]
60
50
40
30
20
10
0
Range [km]
500
300
200
140
100
70
50
1.5
2.0
3.0
4.1
5.0
7.0
10.0
15.0
20.0
Frequency [MHz]
RxMask 11111111
VIPIR WI937_2011191140105.RIQ

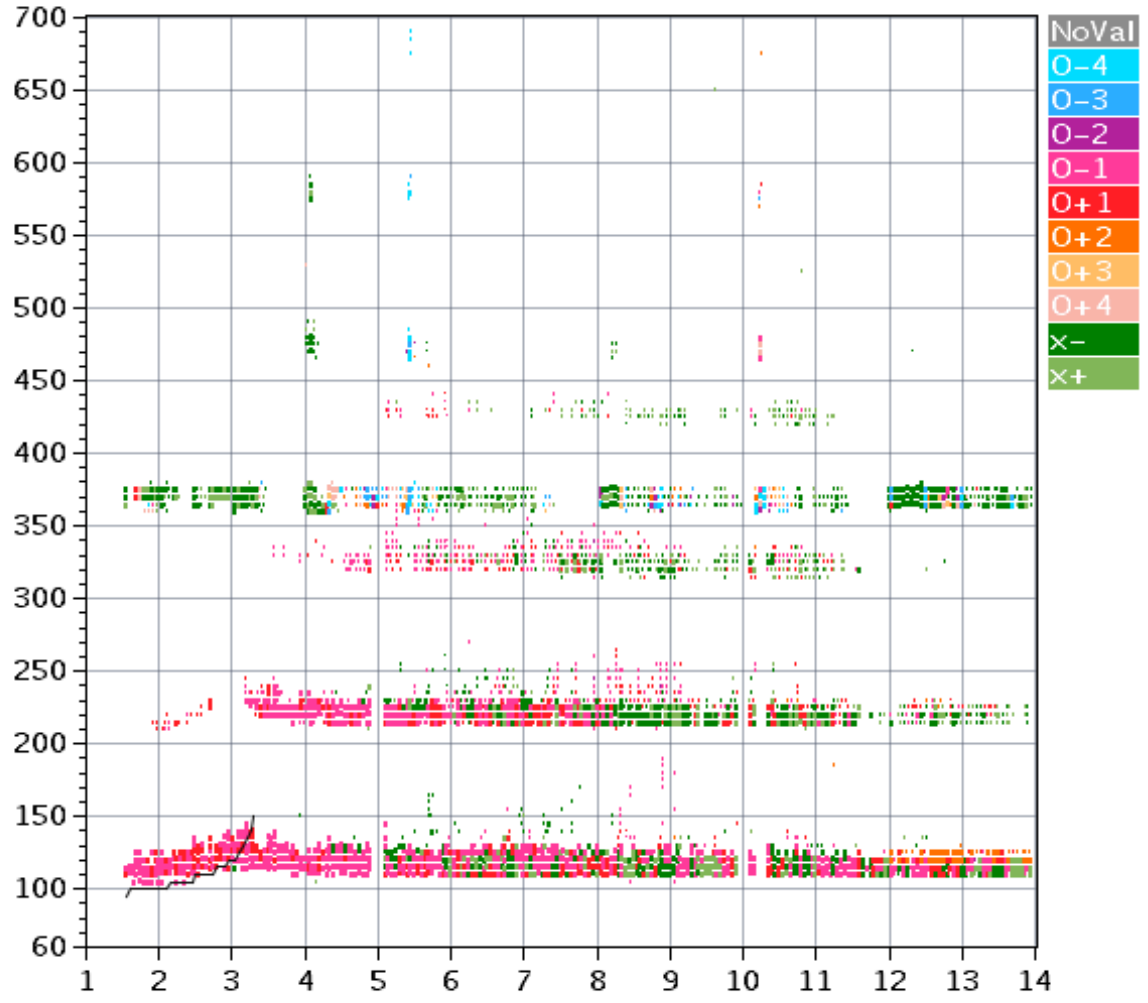
This page reloads the latest ionogram every 2 minutes

Lowell DIGISONDE

Station	YYYY	DAY	DDD	HHMMSS	P1	FFS	S	AXN	PPS	IGA	PS
Wallops Is	2011	Jul10	191	140005	MMM		1	046	200	34+	A1

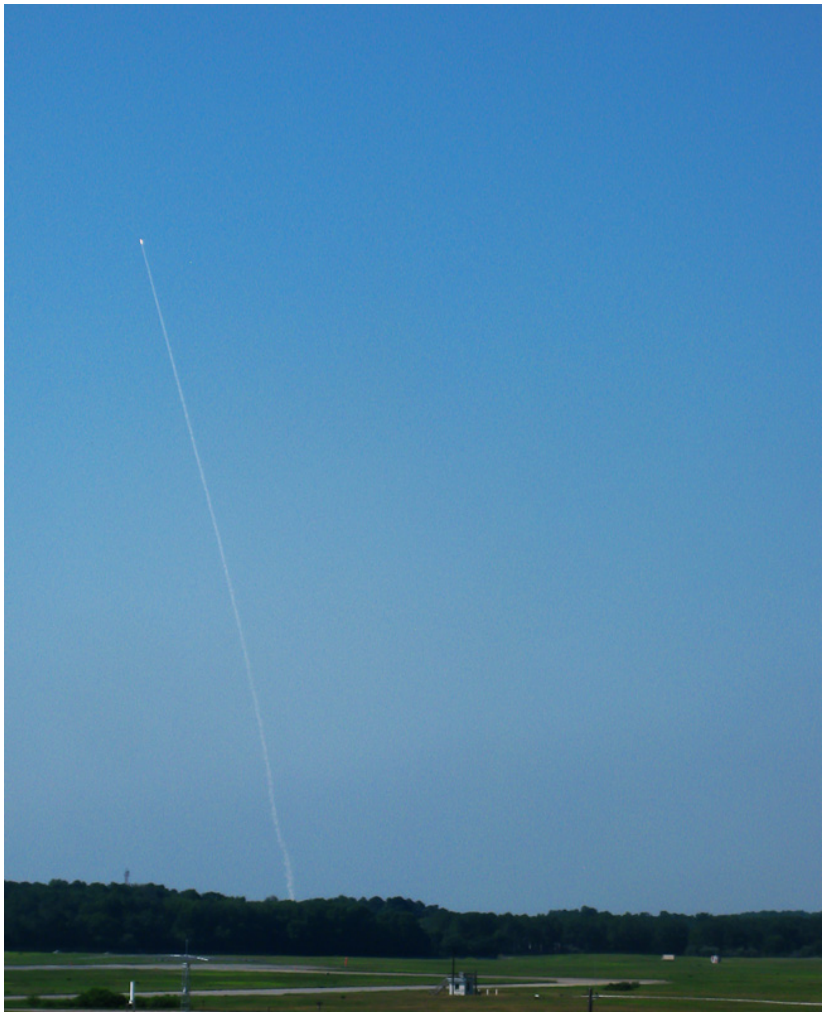
foF2	N/A
foF1	N/A
foF1p	4.46
foE	3.31
foEp	3.22
fxI	N/A
foEs	8.75
fmin	1.55
MUF(D)	N/A
M(D)	N/A
D	3000.0
h`F	N/A
h`F2	N/A
h`E	100.0
h`Es	105.0
hmF2	N/A
hmF1	N/A
hmE	105.7
yF2	N/A
yF1	N/A
yE	15.3
B0	N/A
B1	N/A
C-level	55

Auto:
Artist4
200207



D	100	200	400	600	800	1000	1500	3000	[km]
MUF	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	[MHz]

WP937_2011191140005.MMM / 260fx128h 50 kHs 5.0 km / DGS-256 WP937 081 / 37.9 N 284.5 E Ion2Png v. 1.3.11



Dynamo II Mission

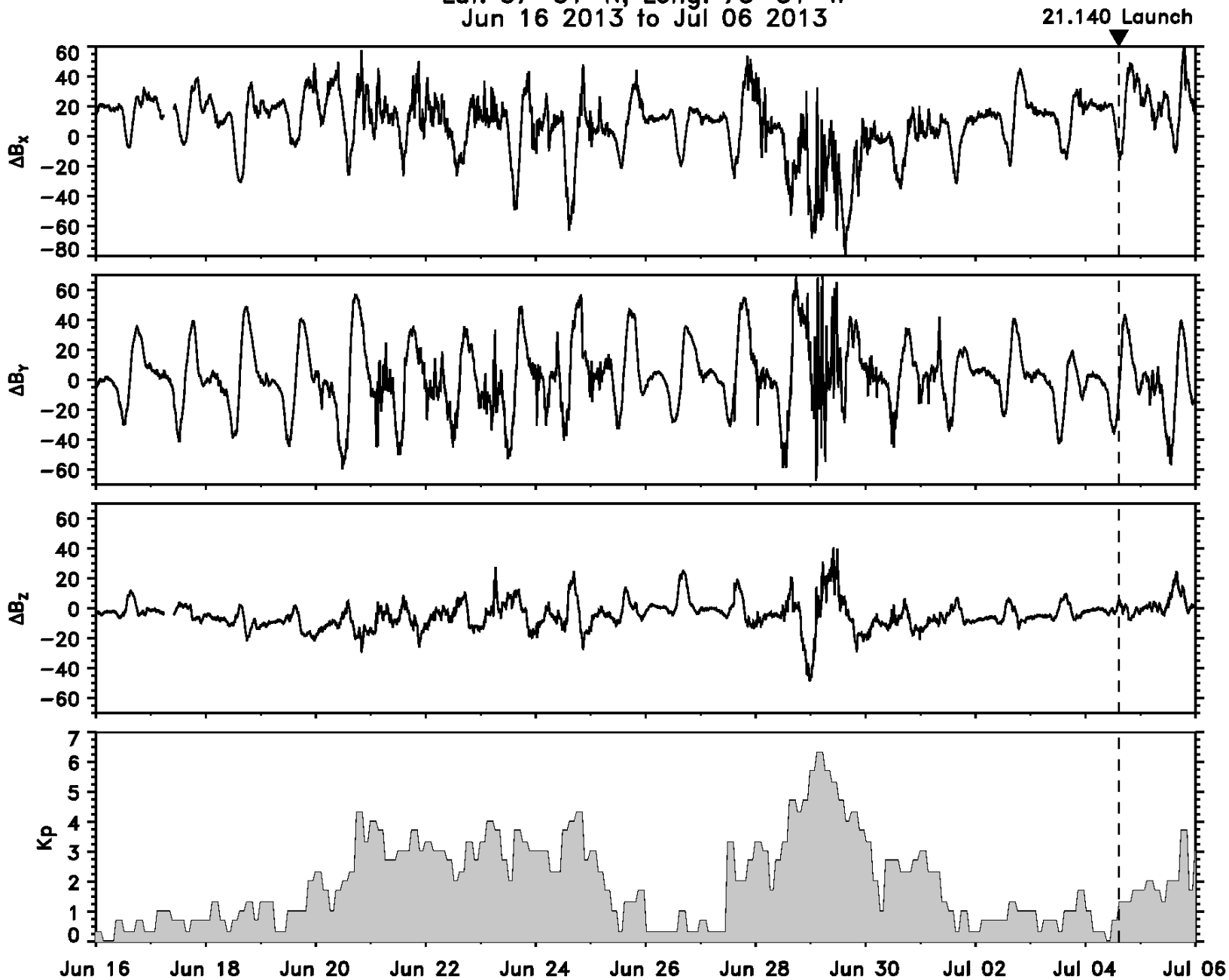
Rockets 21.140 and 41.090

Launch: July 4, 2013

Ground-Based Observations

Rockets 21.140 and 41.090

Launches of July 4, 2013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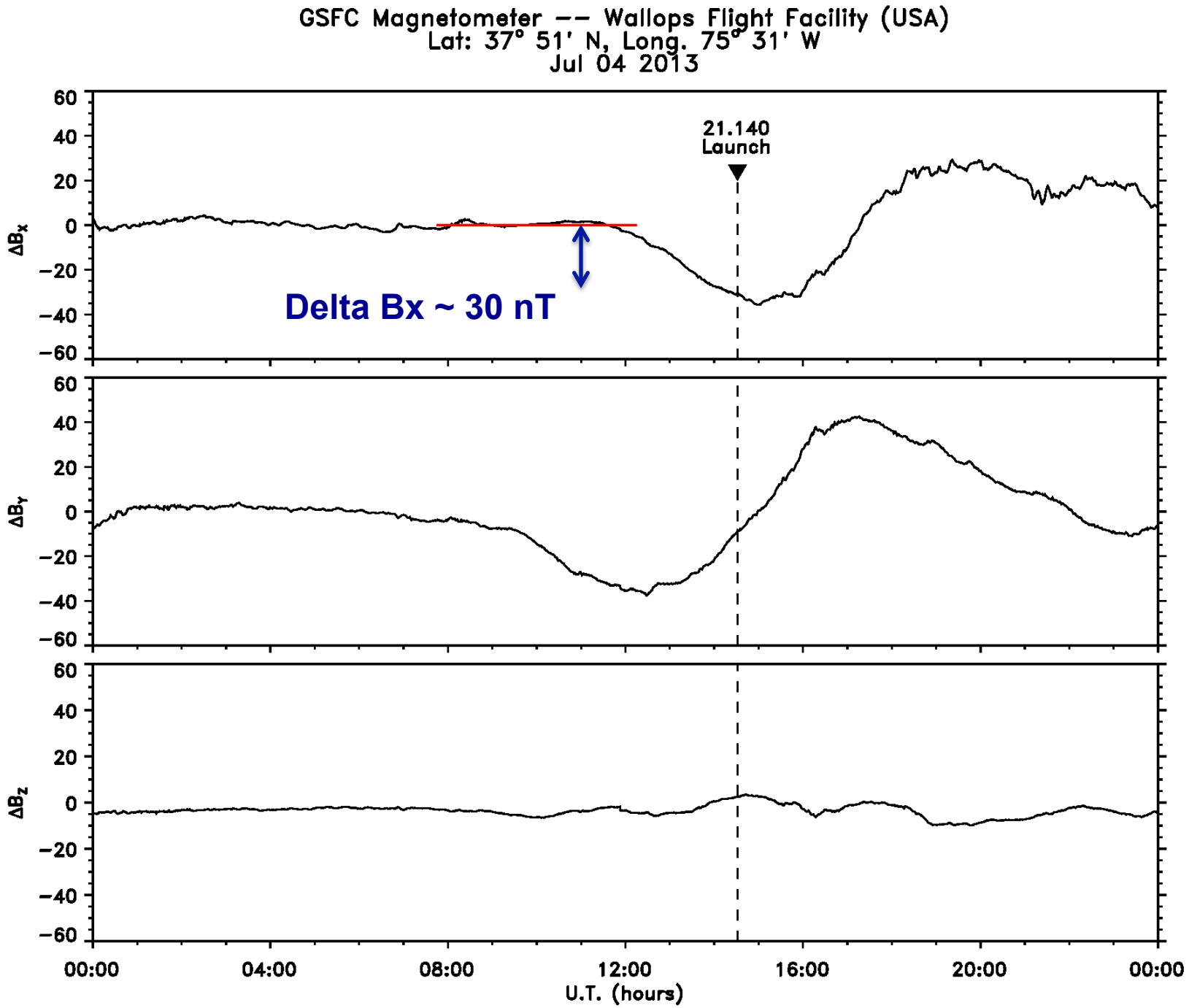
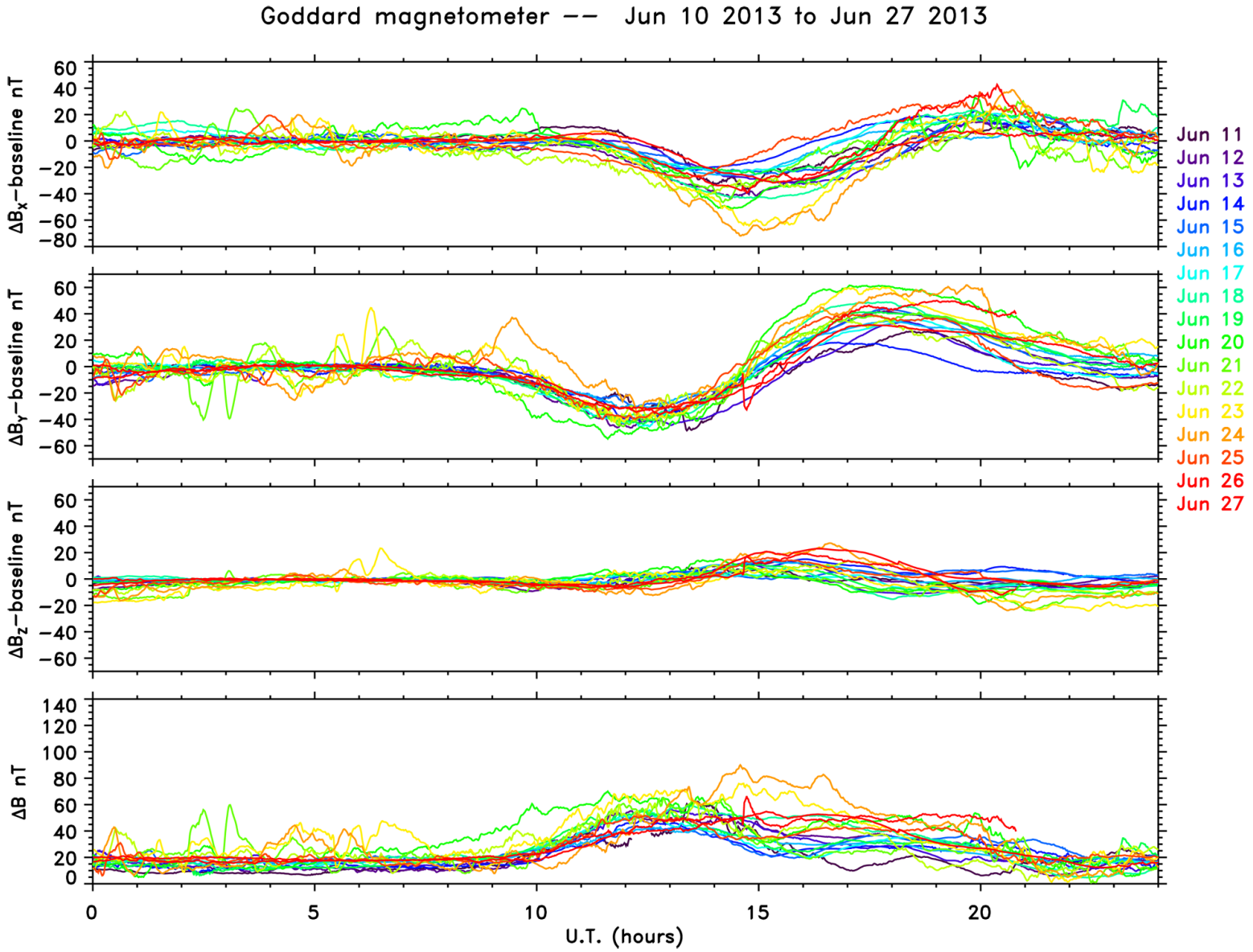
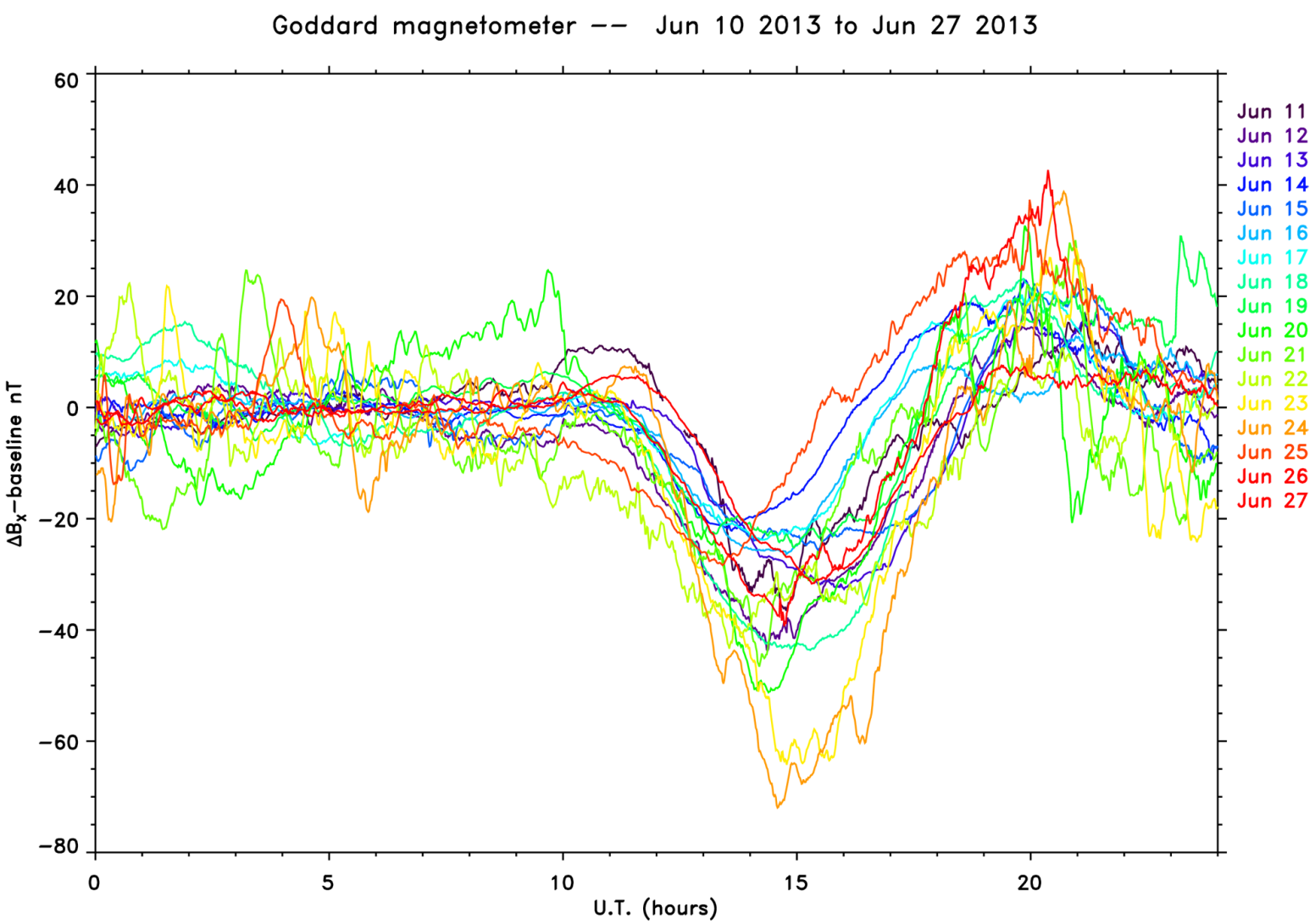
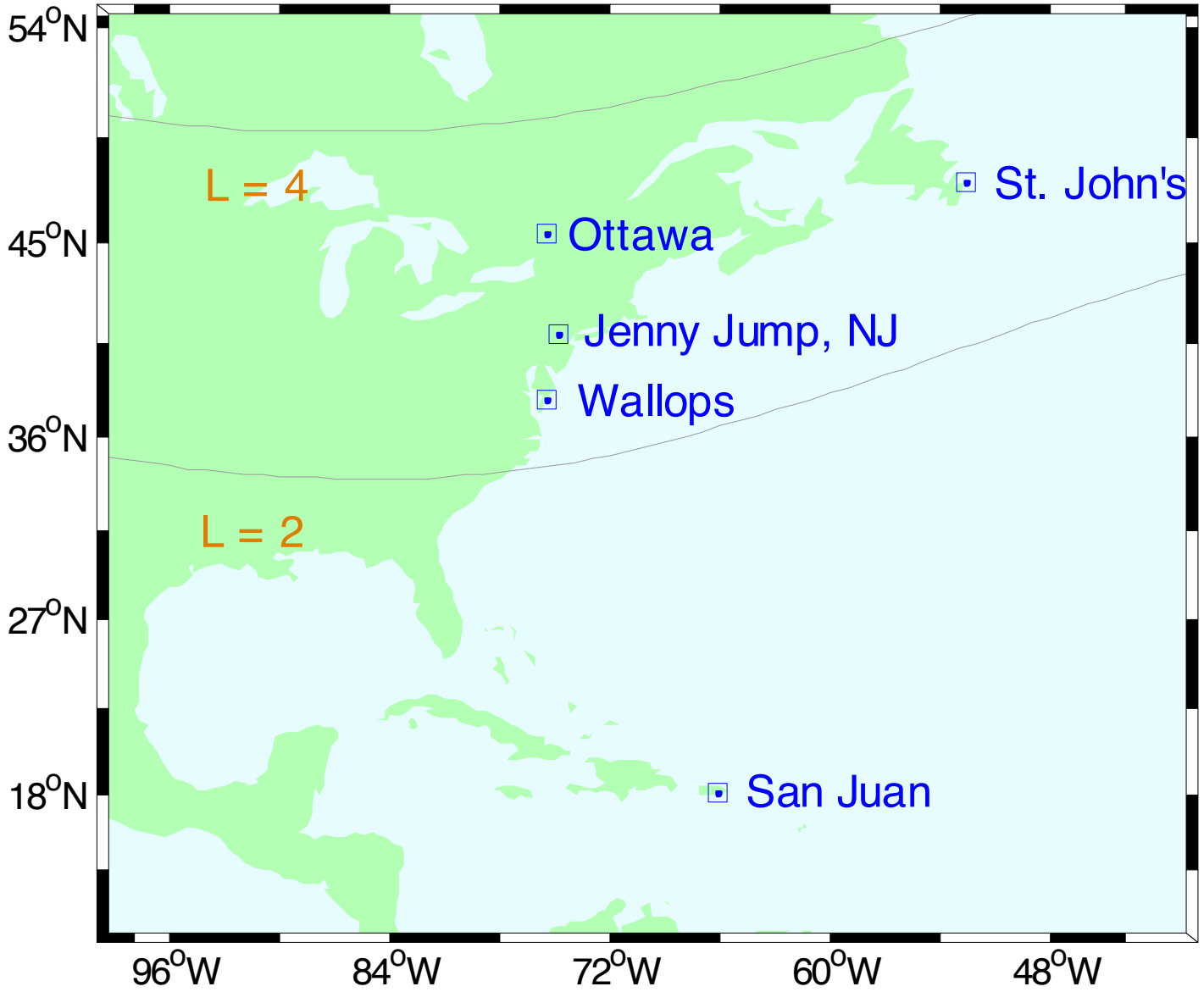
21.140 Launch
ΔBx
ΔBy
ΔBz
Kp
60
40
20
0
−20
−40
−60
−80
7
6
5
4
3
2
1
0
Jun 16
Jun 18
Jun 20
Jun 22
Jun 24
Jun 26
Jun 28
Jun 30
Jul 02
Jul 04
Jul 06

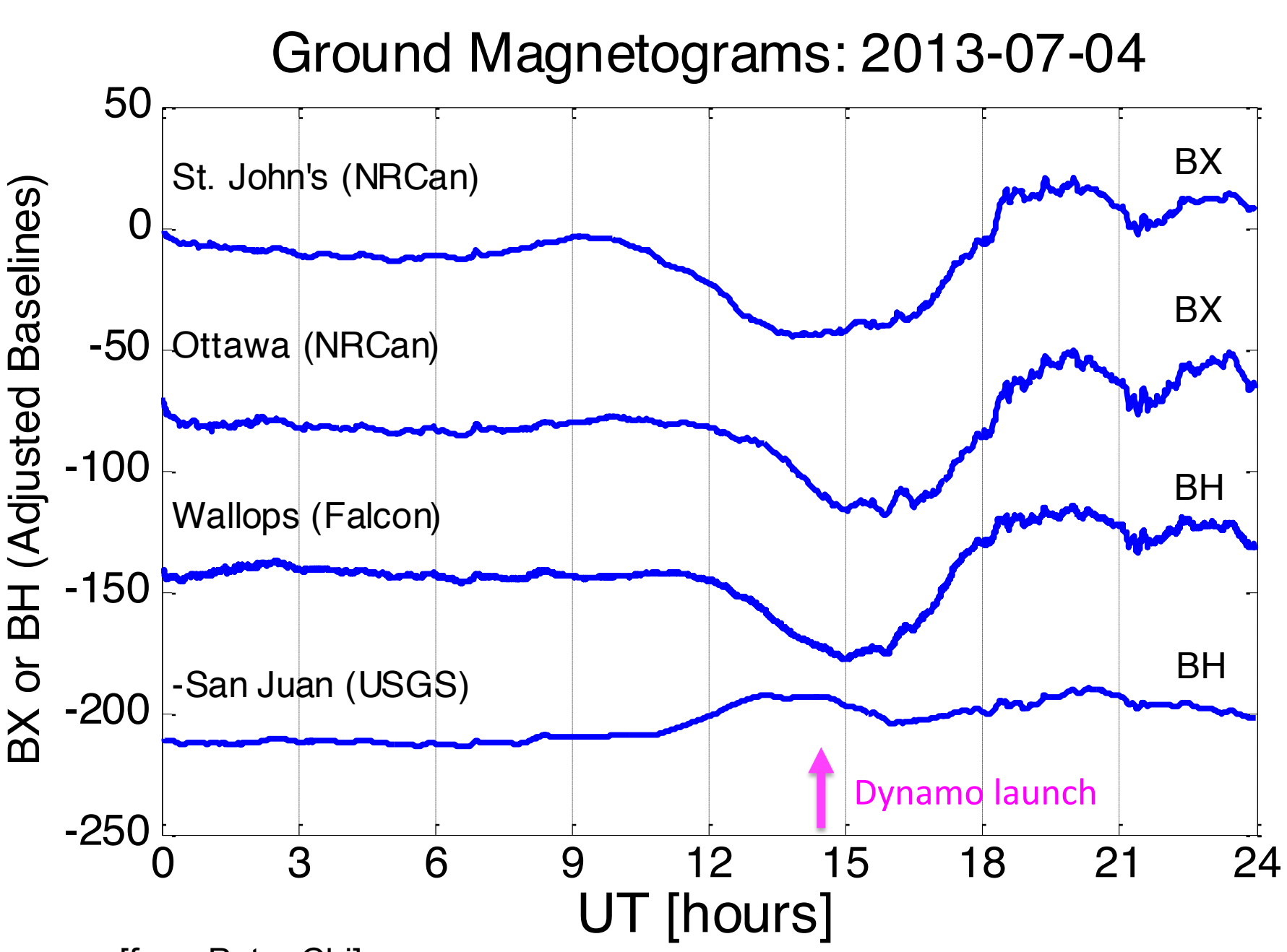

GSFC Magnetometer -- Wallops Flight Facility (USA)
Lat: 37° 51' N, Long. 75° 31' W
Jul 04 2013
21.140
Launch
Delta Bx ~ 30 nT
ΔBx
ΔBy
ΔBz
60
40
20
0
−20
−40
−60
00:00
04:00
08:00
12:00
16:00
20:00
00:00
U.T. (hours)


Goddard magnetometer -- Jun 10 2013 to Jun 27 2013
ΔBx−baseline nT
ΔBy−baseline nT
ΔBz−baseline nT
ΔB nT
U.T. (hours)
Jun 11
Jun 12
Jun 13
Jun 14
Jun 15
Jun 16
Jun 17
Jun 18
Jun 19
Jun 20
Jun 21
Jun 22
Jun 23
Jun 24
Jun 25
Jun 26
Jun 27


Goddard magnetometer -- Jun 10 2013 to Jun 27 2013
60
40
20
0
−20
−40
−60
−80
0
5
10
15
20
U.T. (hours)
ΔBx−baseline nT
Jun 11
Jun 12
Jun 13
Jun 14
Jun 15
Jun 16
Jun 17
Jun 18
Jun 19
Jun 20
Jun 21
Jun 22
Jun 23
Jun 24
Jun 25
Jun 26
Jun 27

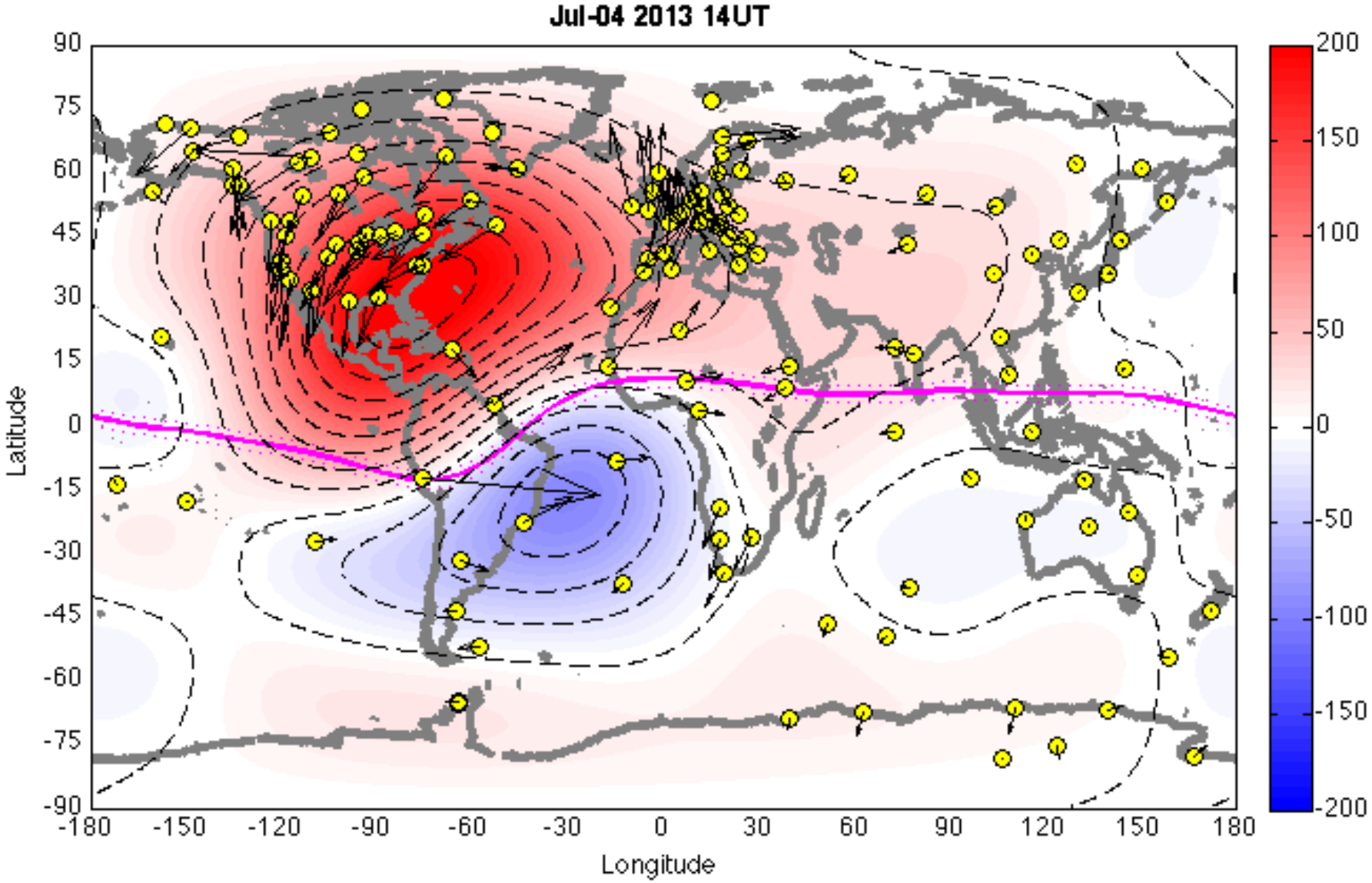


[from Peter Chi]

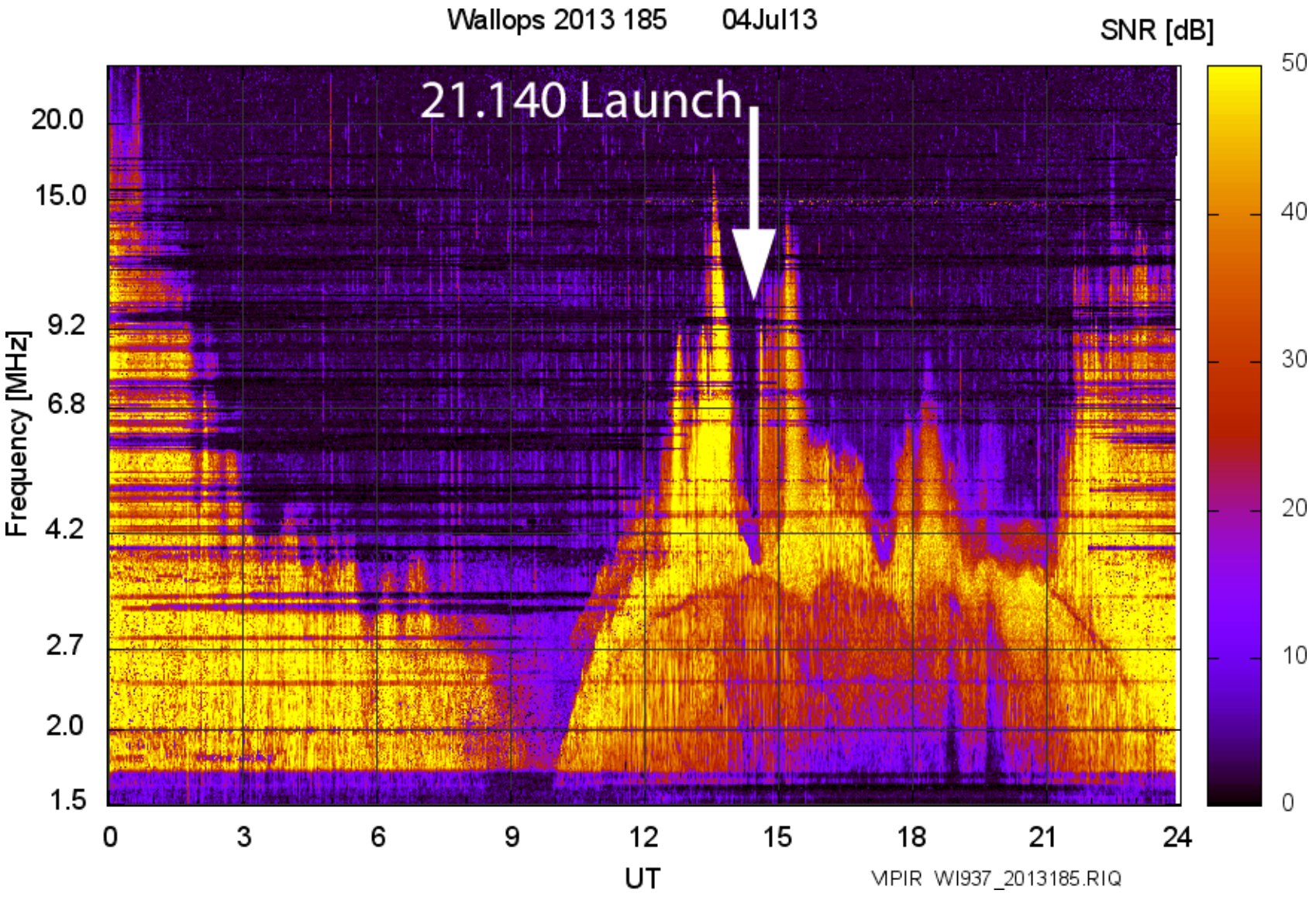


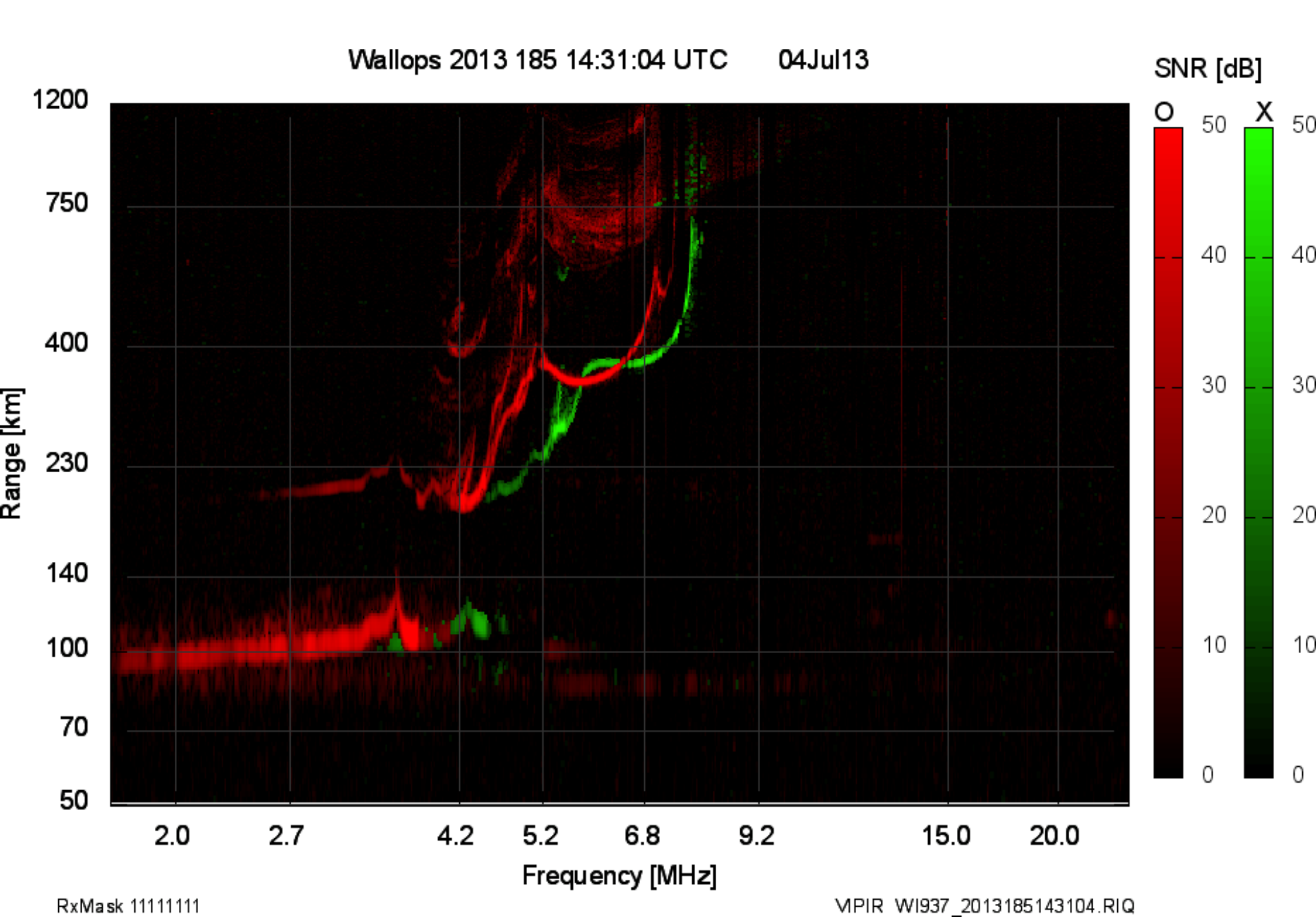
[from Peter Chi]

Current Patterns Derived from Ground-based Magnetometer Data



(Yosuke Yamazaki, Lancaster, UK)


Wallops 2013 185 04Jul13
SNR [dB]
21.140 Launch
Frequency [MHz]
20.0
15.0
9.2
6.8
4.2
2.7
2.0
1.5
0
3
6
9
12
15
18
21
24
UT
VIPIR WI937_2013185.RIQ
50
40
30
20
10
0


Wallops 2013 185 14:31:04 UTC 04Jul13
SNR [dB]
O
X
50
40
30
20
10
0
1200
750
400
230
140
100
70
50
Range [km]
2.0
2.7
4.2
5.2
6.8
9.2
15.0
20.0
Frequency [MHz]
RxMask 11111111
VIPIR WI937_2013185143104.RIQ

Overview of Research Objectives

This research focuses on three main areas of physics in the dayside, lower ionosphere:

1. The atmospheric dynamo and large scale electrodynamics and currents;

2. The very nature of daytime E-region neutral winds and wind shear profiles which are very poorly known;

3. The stability/instability of the dayside, lower ionosphere at mid-latitudes.

Data from Dynamo Rockets: 21.140 (July 4, 2013) and 21.141 (July 10, 2011)

- **Ground-based Observations**

  Magnetometer (GSFC and UCLA/Falcon Magnetometer)
  Ionosonde and VIPIR (Terry Bullett data)

- **In-situ Magnetometer Data and Current Calculations**

  GSFC Fluxgate Magnetometer
  JPL/UCLA Magnetometer

- **Electric Field Observations**

- **Plasma Density (and Electron Temperature?) Observations**

  Langmuir Probe (Jeff Klenzing)
  Impedance Probe (Doug Rowland)

- **Neutral Density, Temperature, Winds** (Jim Clemmons, Aerospace)

- **Ion Mass Composition** (Jim Clemmons, Aerospace)

- **Lithium wind observations** (Miguel Larsen, Clemson; JAXA, Japan)

- **Atmosphere Data from Falling Sphere Experiment** (Chad Fish, USU)

- **Composite Plots of E, J, Ne, Un, E x B and the Dynamo Equation**